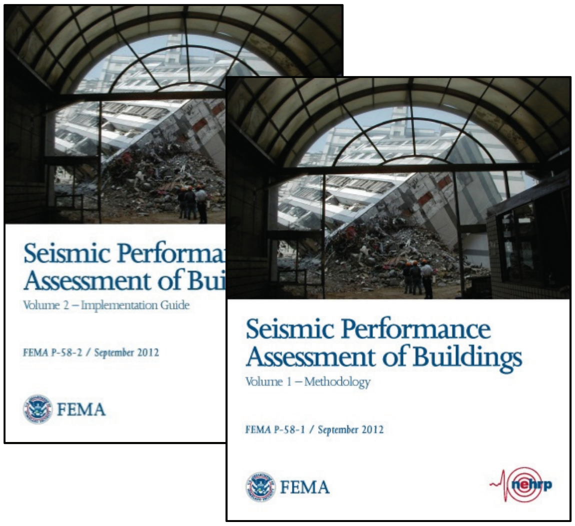

Background Document

FEMA P-58/BD-3.7.15

PACT Beta Test Example: Building B Reinforced Concrete Special Moment Frame Building

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February 23, 2012

Background Documentation

FEMA P-58 Background Documents are a series of reports documenting the technical background and source information for key aspects of the FEMA P-58 methodology and its implementation. These reports were developed over the course of the 10-year ATC-58/ATC-58-1 Projects funded under FEMA Contracts EMW-2001-RP-0056 and HSFEHQ-06-D-1105.

Background Documents were developed by consultants, serving at various levels within the project hierarchy, reporting the results of: (1) decisions on technical development protocols; (2) focused studies on the development of key aspects of the methodology; (3) documentation of recommended procedures; and (4) collection of available data for the development of structural and nonstructural fragilities. They were initially intended to serve as a record of the technical state-of-knowledge at the time they were produced, and as resources for the development of the eventual project reports. As such, they represent a snapshot in time, and may, or may not, match the technical content, recommended procedures, or data incorporated into the final methodology and its implementation.

This Background Document is intended for the purpose of providing supplemental knowledge to users of the FEMA P-58 methodology. Information contained herein has not been independently verified for accuracy as a stand-alone document, and may have been superseded in its final implementation within the methodology. Users of information in this document assume all liability arising from such use.

Notice

Cover illustration – Primary resource documents for the FEMA P-58 *Seismic Performance Assessment of Buildings, Methodology and Implementation* series of products: FEMA P-58-1, *Volume 1 – Methodology*, and FEMA P-58-2, *Volume 2 – Implementation Guide*.

PACT Beta Test Example: Building B
Reinforced Concrete Special Moment Frame Building

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February 23, 2012

1.1 Reinforced Concrete Special Moment Frame Example

1.1.1 Introduction and Overview

In this section a four-story reinforced concrete (RC) special moment frame (SMF) building is evaluated. For purposes of comparison, this building and the site location is made similar to the recent Pacific Earthquake Engineering Research (PEER) Center Benchmarking study (Goulet et al. 2007, Haselton et al. 2008).

1.1.2 Description of Building and Site

Site Location and Site Hazard

The site location and site hazard for this building is described in the PACT Beta Test Overview Report BD-3.7.13.

Building Structural and Non-Structural Design

The building used in this example is a four-story perimeter frame RC SMF building. The specific building model is building ID 1009 from a recent dissertation by Haselton (Haselton and Deierlein, 2007) and is designed according to the ASCE7-05 (ASCE 2005) and ACI 318-05 (ACI 2005) building codes. This building is almost identical to the building used in the PEER Benchmark study, but the design differs slightly (e.g. the fundamental period of this building is 1.13 seconds and the Benchmark building fundamental period is 1.02 seconds). Even so, the building is similar enough to make general comparisons between the PACT loss predictions completed in this section and those of the recent PEER Benchmarking study.

The plan and elevation views of the Benchmark building (which is similar to building ID 1009) are shown in Figure 1-1 and Figure 1-2.

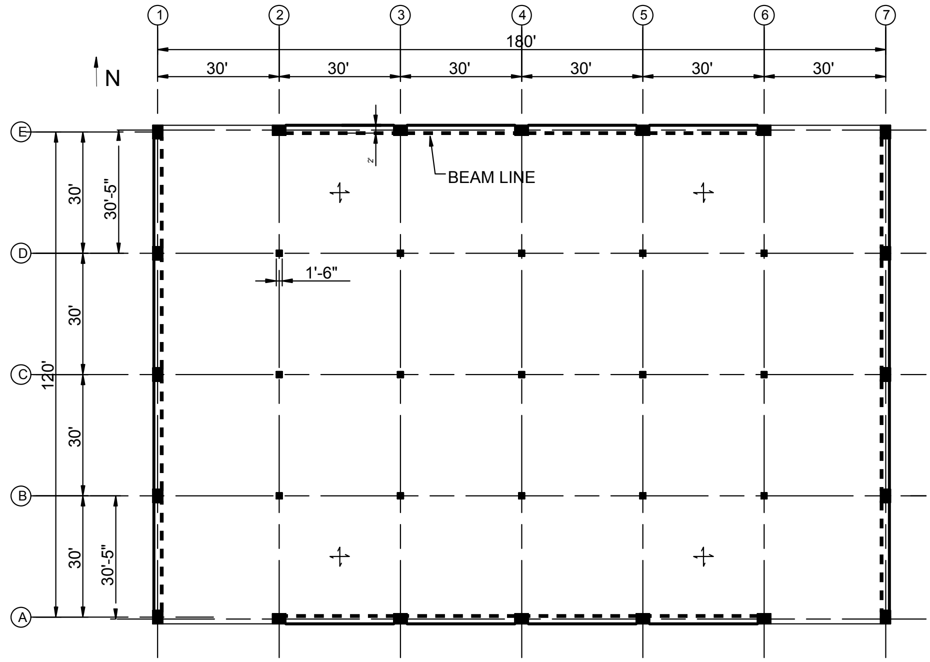


Figure 1-1 Plan view of one frame of Benchmark building (from Haselton et al. 2008).

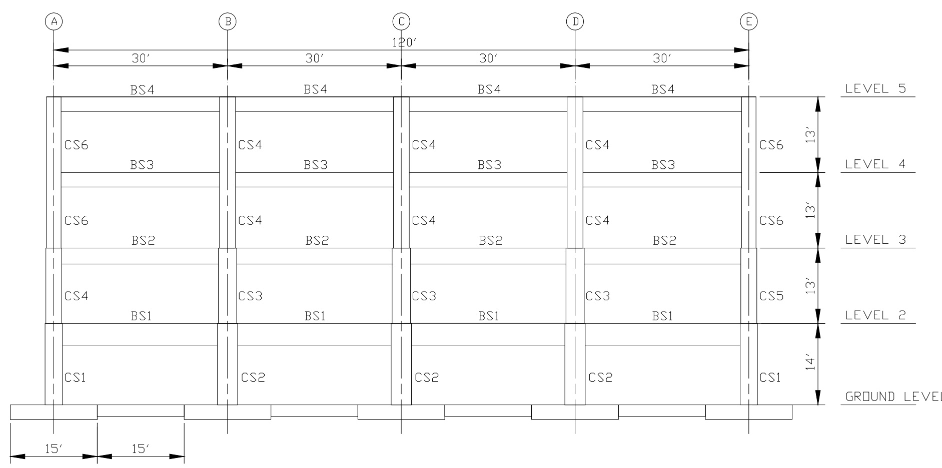


Figure 1-2 Elevation view of one frame of Benchmark building (from Haselton et al. 2008).

1.1.3 Documentation of PACT Input for the Baseline Building

Decisions and Input information for the PACT Project Manager have been documented below, categorized by the Project Manager tabs, in the order that they appear in the PACT user interface.

Project Information

The decisions in the Project Information tab are to select the Region Cost Multiplier, the Date Cost Multiplier, and the Engine Random Seed Value.

For this study, the Region Cost Multiplier was set equal to unity, because, although the study is for a specific building site, it is also meant to be generic. An analysis of any specific building should certainly consider the relative regional costs of labor and construction materials in the area, even though this was not done in this generic example study. Additionally, the elevated costs of earthquake damage repairs due to the high demand for labor and construction materials immediately following and earthquake is not directly considered by PACT, but it could be indirectly accounted for by adjusting the Region Cost Multiplier.

For computing loss estimates of a particular building, the Date Cost Multiplier should to be based on long-term economic trends, the expected life-time of the building, and the time-value of money. However, for simplicity in this example study, the Date Cost Multiplier was set equal to unity.

All of the PACT projects used in this study utilized a seed value of 0. Such a seed value causes the PACT engine to generate a random seed at the beginning of each evaluation of the project, for use in its random number generator; this means that the same project can be analyzed multiple times and yield different results for each of the evaluations. For each evaluation included in these Building B examples (both the baseline and the sensitivity studies), a minimum of three runs were completed each with a seed value of 0; the results of the runs were then averaged to obtain a more stable prediction of the average results.

Building Information

Multiple variations of the same building were modeled in PACT for the purpose of testing the PACT software and completing sensitivity studies. The four-story building used in this study is building ID 1009 from Haselton and Deierlein (2008) and is similar to (but not exactly the same as) the four-story "Design A" building used in the PEER Benchmarking study (Goulet et al. 2007, Haselton et al., 2008). This building is a representative four-story office building with perimeter reinforced concrete (RC) special moment frames (SMFs). The plan dimensions are 120' x 180', giving the building a total plan area of 21,600 sq. ft and a total floor area of 86,400 sq. ft. The bottom story height is 14 ft and all other story heights are 13 ft. Two versions of this building are used in the PACT projects of this study - one to represent the Benchmark study building as closely as possible, and a second project to best estimate the structural damage and loss according to the ATC-58 Normative Quantities Worksheet. A comparison of these two building versions is included later in Section 1.1.7; the primary differences are the quantities and content in the building and the hazard curve used for the assessment (either from the USGS or from the PEER Benchmarking study).

For the baseline model, the total replacement time was estimated to be 400 days. For all of the PACT projects, the fields ‘Max Workers per sq. ft.’ and ‘Total Loss Threshold (As Ratio of Total Replacement Cost)’ were left equal to their PACT default values, 0.001 and 1.0, respectively. Also, the values of ‘Height Factor’, ‘Hazmat Factor’, and ‘Occupancy Factor’ were left to their PACT default values of unity.

The total replacement cost and the core and shell replacement cost for the baseline project were $21.6 million and $8.64 million, respectively. These cost estimates were based on ‘rule of thumb’ estimates of $250 per sq. ft. to replace a typical office building and $100 per sq. ft. to replace just the core and shell.

As part of the comparison to the PEER Benchmark project results, a PACT analysis was also completed with the total replacement cost set equal to the total building cost that was used for the Benchmark project, $8.9 million. For these checks, the core and shell replacement cost was estimated to be roughly half of the total replacement cost, $4.5 million.

Population

The building population in all of the projects was modeled using the preinstalled ‘Commercial Office’ population model available in PACT. The fraction of each floor that was modeled as ‘Commercial Office’ was 1.0, meaning that the entire building’s population was ‘Commercial Office.’ The ‘Peak number of occupants per 1000sf’ and ‘Population Dispersion’ fields were left at their PACT default values for commercial office populations, 4.0 and 0.2, respectively.

The default PACT population model was used, which includes a calendar with population densities that are a function of the day and the time of day, based on normative values. The PACT evaluation engine randomly selects days and times for each realization of an analysis and uses the corresponding population density to compute injuries and casualties.

Fragilities

The 'Fragilities' tab is used to select performance groups. The user can either select fragilities for each floor, or select fragilities for the entire building. After selecting, the user must select the population model that the fragility applies to, and may select if the fragility should be in either a single direction or both directions. These input Performance Groups are documented in the following subsections for the baseline Building B analyses.

Performance Groups: General Information

The fragilities that were used for the baseline project were selected to match the fragilities that were used in the Benchmark study (Goulet et al. 2007, Haselton et al. 2008) as closely as possible. However, the additional fragilities that are available in PACT (that were not used in the Benchmark study) were also added, consistent with the ATC-58 Normative Quantities Worksheet. Therefore, the process for choosing fragilities was similar to how it would be done for a real building assessment - known quantities were modeled as closely as possible with the available PACT fragilities, and unknown quantities were estimated based on normative values.

The following subsections describe the performance groups used in the Benchmark study and a summary of the corresponding fragilities that were selected from the PACT fragility database.

Performance Groups: Beam and Column Elements of Perimeter Moment Frames

In the Benchmark study (Goulet et al. 2007, Haselton et al. 2008), fragility models were used for each discrete beams and columns element. However, the preinstalled fragilities in PACT are set up differently. Rather than modeling beams and columns separately, fragilities are set up according to the number and type of joints in each story. Beam sizes are never considered; instead, the user must select fragilities based on approximate size and type of column, and whether the joint is an interior or exterior joint.

Due to the fact that the RC SMF building meets the design requirements of ACI 318-05 (ACI 2005), the ACI 318 SMF column fragilities were utilized, for which joint shear failure is not expected. The preinstalled PACT fragilities include three stages of damage, similar to the fragilities used in the Benchmark study. The joint fragilities in the PACT project were selected such that the column areas were similar to those in the Benchmark study, as summarized in Table 1-1.

Table 1-1 Summary of RC SMF Fragilities

Story	Fragility	Quantity (Each Direction)
1	B1041.002a 24x36, ACI 318 SMF, beam on one side	2
	B1041.003b 36x36, ACI 318 SMF, beam both sides	3
2	B1041.002a 24x36, ACI 318 SMF, beam on one side	1
	B1041.002b 24x36, ACI 318 SMF, beam both sides	3
	B1041.003a 36x36, ACI 318 SMF, beam one side	1
3	B1041.001a 24x24, ACI 318 SMF, beam on one side	2
	B1041.002b 24x36, ACI 318 SMF, beam both sides	3
4	B1041.001a 24x24, ACI 318 SMF, beam on one side	2
	B1041.002b 24x36, ACI 318 SMF, beam both sides	3

Performance Groups: Gravity Columns and Slab-Column Connections

The Benchmark study building had a two way post-tensioned slab supported by 18” by 18” gravity columns. The columns were assumed to have the minimum code-required confinement for gravity columns. The preinstalled fragilities for PACT are based on slab and gravity column type, but are independent of column size. The most appropriate fragility available in the Beta version of PACT was No. B1049.031, which is for post-tensioned flat slabs with 0<Vg/Vo<0.4 and supported by columns with shear reinforcing. Fifteen gravity columns were designated for each story of the building.

Performance Groups: Dry Wall Partitions and Finishes

The Benchmark study used drywall partitions with 5/8” wallboard on 3 5/8” metal studs at 16” O.C. with screw fasteners, and the walls fixed at the top and bottom. In the Benchmark study, fire-rated walls were considered to be robust and not considered in the loss analysis. The preinstalled PACT fragilities available were less specific, so a general gypsum wall fragility was used (C1011.001a) for partitions fixed at the top and bottom. The PACT fragilities were based on 13’x100’ panels, as opposed to the Benchmark test, which were based on 8'x8' panels. In order to have the best possible consistency for comparison, the same square footage of partitions was used in PACT as in the Benchmark study. The Table 1-2 below was generated using the above stated method and reports the computed quantities that were used in the PACT projects.

Table 1-2 Partition Quantities Comparison

Benchmark Study				PACT Study		
Level	Total Panels Each Direction	Panel Dimensions	Total Panel Area	Total Panels Each Direction	Panel Dimensions	Total Panel Area
1	134	8x8 ft	8,576 sq ft	6.6	100x13 ft	8,576 sq ft
2	181	8x8 ft	11,584 sq ft	8.9	100x13 ft	11,584 sq ft
3	181	8x8 ft	11,584 sq ft	8.9	100x13 ft	11,584 sq ft
4	181	8x8 ft	11,584 sq ft	8.9	100x13 ft	11,584 sq ft

Interior paint was also modeled in the Benchmark report, but no 'interior paint' fragility was available among those preinstalled in PACT. However, the first damage state for the partition fragility in PACT required repainting of both sides of the partition, so the interior paint fragility is considered to be included within the PACT partitions fragility. The quantity of this fragility has been calculated from the Benchmark Study, and not the ATC-58 Normative Quantities Worksheet. The Normative Quantities Worksheet suggested that 21.6 panels be used in each direction on every floor.

Also included in the PACT model is the Wall Partition Fragility (C3011.002C) entitled "Gypsum + Ceramic Tile, Full Height, Fixed Below, Slip Tracks Above w/ returns (friction connection);" this was included with a quantity of 1.63 panels, with the panels each being a size of 9' by 100'. This was added based upon the ATC-58 Normative Quantities Worksheet. It is added to the above partition walls, rather than replacing them; depending on actual layout of the building, it is possible that this could over predict the partition cost by around 10%.

Performance Groups: Exterior Glazing

The Benchmark building used 5'x6' lightweight aluminum-frame glazing panels. The glazing fragilities in PACT were far more specific than the fragilities used for Benchmark report, so the specific type was selected based solely on judgment. The PACT fragility chosen for the comparison study was for 5'x6' insulated glass units with a single pane that is 0.25" thick each and with 0.43" frame clearance (B2022.001). Table 1-3 lists the quantities of glazing assigned to each story of the building.

Table 1-3 Glazing Quantities

PACT Study- Glazing				
Story	Panel Dimensions	Units	Total Direction 1	Total Direction 2
1	5x6 ft	Each	168	112
2	5x6 ft	Each	156	104
3	5x6 ft	Each	156	104
4	5x6 ft	Each	156	104

Performance Groups: Acoustical Ceilings

The Benchmark study and the comparative PACT Projects used in these examples both utilized a total of 81,000 sq. ft. of acoustical tile ceiling for the entire building. The Benchmark study ceiling was described as follows:

> *"…consists of a grid-work of aluminum channels in the shape of an upside-down "T," connected to the diaphragm above with splay wires that, in theory, provide lateral-force bracing along with vertical compression struts. These channels are in a regularly spaced pattern made up of a 2-ft by 4-ft grid and support lightweight acoustical ceiling tiles."* (Haselton et al. 2008).

The corresponding PACT fragility that was selected is:

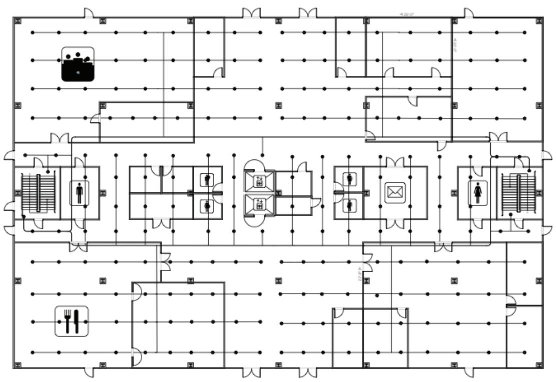
> "*C3032.003b, Suspended Ceiling, SDC D, E (Ip=1.0), Area (A): 250 < A < 1000, Vert & Lat support. Costing for each 600 SF Unit, Suspended Lay-in Acoustic Tile Ceiling, Support: Vertical hanging wire, diagonal wires, and compression posts, 2 inch wide ledger support angles at wall and oversize holes around tile openings*" (PACT Fragility Manager).

These fragilities were placed upon the first floor through the fourth floor, with the check box selected to use the demands from the floor above. A value of 36 units per floor was used, totaling 21,600 sq. ft. per floor, as suggested by the Normative Quantities Worksheet; this is a small overestimation of the actual quantity present in the example building.

Performance Groups: Automatic Sprinklers

In the Benchmark study, the Benchmark office building was categorized to have "light fire hazard" according to the National Fire Protection Association's Automatic Sprinkler Systems Handbook (NFPA-13 2002). The area/density approach of the NFPA handbook (NFPA-13 2002) was used to design the sprinkler system. Assuming that each sprinkler provides 125 square feet of coverage, the calculation assumes that a minimum of 16 sprinklers operate simultaneously during a fire. In the Benchmark study, the piping necessary for these requirements was found to be 2,241 linear feet in the first story and 2,418 linear feet for all stories above. The weight of the sprinkler pipe is supported by hanger rods and the pipes are braced every 12 feet to restrain lateral and longitudinal displacements (Haselton et al. 2008). The sprinkler layout from the Benchmark building non-structural design is shown in Figure 1-3.

(a)



(b)

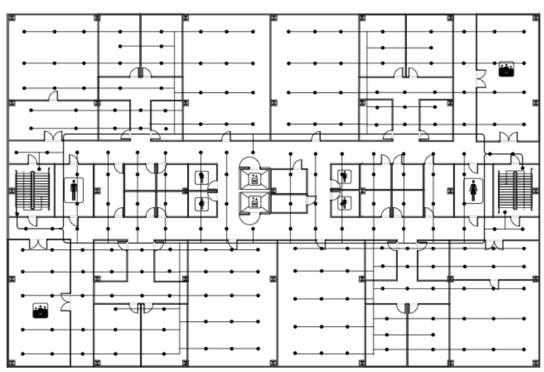


Figure 1-3 Automatic sprinkler piping systems for (a) floor two (the ground story), and (b) floors three through five (from Haselton et al. 2008).

For the fire sprinklers, the utilized fragility is D4011.013a, "Fire Sprinkler Water Piping - Horizontal Mains and Branches - New Style Vitaulic / Threaded Steel, SDC D, E, or F " (Note that D4011.013b is used to accompany D4011.013a, where D4011.013a is the piping fragility and D4011.013b is the bracing fragility.). The total length of fire sprinkler piping used for each level in the Benchmark study was divided by the number of floors and then by 1000 feet (the length per unit use by the PACT fragility) to arrive at the final input quantity of 2.2 fire sprinkler units in the first story and 2.4 units in the upper stories. The ATC-58 Normative Quantities Worksheet recommends that a quantity of 4.32 units be used for each story; in this case, the larger normative quantities were used in the PACT model.

Performance Groups: Elevators

The Benchmark building had two hydraulic elevators. Even so, based on the ATC-58 Normative Quantities Worksheet, one traction elevator was used in the PACT model (fragility D1014.010 was included at each story).

Performance Groups: Additional Performance Groups

In addition to choosing fragilities that were represented in the PEER Benchmark study building, additional fragilities were also added to the baseline project, as recommended by the ATC-58 Normative Quantities Worksheet. This normative quantity database contains the tenth, fiftieth, and ninetieth percentile quantities of the content typically found in buildings of various size and type; the fiftieth percentile (median) quantities were used for these examples. Table 1-4 summarizes the normative quantities and corresponding PACT Performance group quantities that were used for the additional fragilities.

It is noted that some of the normative quantities that were included in the normative quantity list were not yet available in the PACT fragility manager, so they were not included in this example. Additional user-defined fragilities could have been created, but this was not done because it is not expected that such additions would significantly affect the loss predictions.

Table 1-4 Summary of Additional Fragilities

General Descr.	Unit	Location	Qnt.	PACT Fragility Code	Fragility Description, From PACT
Lighting	EA	Each Diaphragm	648	C3034.002	Suspended Pendulum Lighting - seismically rated
Elevator	EA	Each Diaphragm	1	D1014.010	Traction elevator
Cold Water Pipe	1,000 LF	Each Diaphragm	1.23	D2021.013a	Domestic Cold Water Piping (dia > 2.5 inches), SDC D,E,F, Piping Fragility
Cold Water Pipe	1,000 LF	Each Diaphragm	1.23	D2021.013b	Domestic Cold Water Piping (dia > 2.5 inches), SDC D,E,F, Bracing Fragility
Waste Pipe	1,000 LF	Each Diaphragm	1.23	D2031.013b	Sanitary Waste Piping - Cast Iron w/flexible couplings, SDC D,E,F, Bracing Fragility
HVAC Ducting	1,000 LF	Each Diaphragm	1.62	D3041.021c	HVAC Stainless Steel Ducting less than 6 sq. ft in cross sectional area, SDC D, E, or F
HVAC Ducting	1,000 LF	Each Diaphragm	0.43	D3041.022c	HVAC Stainless Steel Ducting - 6 sq. ft cross sectional area or greater, SDC D, E, or F
HVAC Drops / Diffusers	EA	Each Diaphragm	19.44	D3041.032c	HVAC Drops / Diffusers without ceilings - supported by ducting only - No independent safety wires, SDC D, E, or F
VAV	10 Units	Each Diaphragm	16	D3041.041b	Variable Air Volume (VAV) box with in-line coil, SDC C
Steam Piping	1,000 LF	Each Diaphragm	1.92	D3043.013b	Domestic Steam Piping - Small Diameter Threaded Steel - (2.5 inches in diameter or less), SDC D, E, or F, Bracing Fragility
Hot Water Piping	1,000 LF	Each Diaphragm	1.92	D3044.013a	Domestic Hot Water Piping - Small Diameter Threaded Steel - (2.5 inches in diameter or less), SDC D, E, or F, Piping Fragility
Hot Water Piping	1,000 LF	Each Diaphragm	0.76	D3044.023a	Domestic Hot Water Piping - Large Diameter Welded Steel - (greater than 2.5 inches in diameter), SDC D, E, or F, Piping Fragility
Hot Water Piping	1,000 LF	Each Diaphragm	0.76	D3044.023b	Domestic Hot Water Piping - Large Diameter Welded Steel - (greater than 2.5 inches in diameter), SDC D, E, or F, Bracing Fragility
Fire Sprinkler	100 Units	Each Diaphragm	1.94	D4011.033a	Fire Sprinkler Drop Standard Threaded Steel - Dropping into unbraced lay-in tile soft ceiling - 6 ft. long drop maximum, SDC D, E, or F
Concrete Tile Roof	100 SF	Roof	58.32	B3011.011	Concrete tile roof, tiles secured and compliant with UBC94
Chiller	EA.	Roof	1	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
Cooling Tower	EA.	Roof	1	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
Air Handling Unit	EA.	Roof	4	D3052.013i	Packaged Air Handling Unit - Capacity: 10000 to <25000 CFM - Equipment that is either hard anchored or is vibration isolated with seismic snubbers/restraints - Combined anchorage/isolator & equipment fragility

Collapse Fragility: General

In PACT, there is an option under the 'Collapse Fragility' tab to include or exclude potential collapse in the assessment. For all of the PACT projects used in this example, potential collapse was included in the assessments.

Collapse Fragility: Estimating the Median and Dispersion of Collapse Capacity

To estimate the median and variability in collapse capacity, the collapse results for the eight intensity levels were utilized. The eight intensity levels were selected according to the ATC-58 Methodology guidelines and then eight sets of twenty ground motions were then selected and scaled for each of the eight intensities (as described in the PACT Beta Test Overview Report, BD-3.7.13). Due to the fact that the building was modeled only as a simplified two-dimensional frame, the nonlinear dynamic analyses were completed for each of the orthogonal components of each ground motion, and the building was considered to have collapsed if either of the components caused collapse of the two-dimensional model.

Using collapse data shown in Table 1-5 and Figure 1-4, the ground motion intensity for median collapse was estimated to be 1.35g (in terms of spectral acceleration at the fundamental period of 1.13s). The logarithmic standard deviation of collapse capacity was set to be 0.5 (the dispersion used for the PACT input), which includes both the record-to-record variability and some nominal amount of additional uncertainty (based on the recommendations for FEMA P695, 2009, for RC SMF buildings). It is noted that the structural model used for this example assessment differs slightly from the structural model used in previous studies for the same building (FEMA 2009); therefore, the estimated 1.35g median collapse capacity is not directly comparable to those previous studies.

Note that if detailed collapse capacity estimates were not available for a specific building, as is the case when only linear analyses are utilized, users may make a reasonable estimate of collapse capacity. For example, the FEMA P695 study (FEMA 2009) has shown that modern buildings should have a median collapse capacity that is approximately twice the Maximum Considered Earthquake ground motion level.

Collapse Fragility: Residual Drift Capacity

The median and dispersion of the residual drift capacity was set at the default values of 1% (0.01) and 0.30, respectively. For each of the ground motion intensity levels, Table 1-5 and Figure 1-4 report the resulting probabilities that the building will be non-repairable due to excessive residual drifts, collapse, or a combination of the two modes.

Table 1-5 Collapse and Residual Drift Ratios from PACT Results for Each Intensity Level

Intensity	Sa (T_1) (g)	Percent Collapsed	Percent Unrepairable Residual Drift	Percent Unrepairable
1	0.158	0%	2%	2%
2	0.387	4%	1%	5%
3	0.615	13%	13%	26%
4	0.843	25%	52%	77%
5	1.071	37%	42%	79%
6	1.299	48%	39%	87%
7	1.528	57%	39%	96%
8	1.756	65%	35%	100%

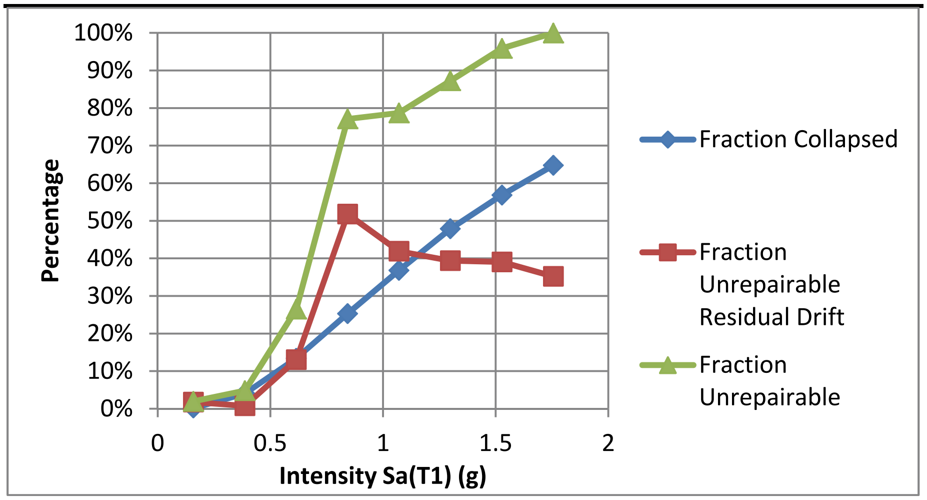


Figure 1-4 Cumulative Collapse and Residual Drift Distribution from Structural Analysis

Structural Analysis Results: Non-Linear Structural Analysis Results

For nonlinear analysis, 11 ground motions were selected for each of the eight different intensities using the Conditional Mean Spectrum (CMS) approach, as is recommended by the ATC-58 Methodology. An overall summary of the structural response predictions from nonlinear time-history dynamic analysis are presented in the Appendix Section 1.1.8 for each of the eight ground motion intensity levels. This includes both median response values and the logarithmic standard deviations of the responses.

Structural Analysis Results: Non-Directional Demand Vectors

PACT is set up to compute the non-directional demand vectors (e.g. peak interstory drift in any direction, rather than in the orthogonal X or Y directions) using the maximum of the directional demand vectors (e.g. peak interstory drifts in the X and Y directions) multiplied by a user-input multiplication factor. In this example, the non-directional demand vectors were computed using an input factor of 1.2.

When non-directional demand vectors are compute in PACT, the dispersion values are computed as an average of the dispersion values between the two directional demand vectors (e.g. see Section 1.1.8 demand vector examples, where "Direction Three" is for the non-directional demand vectors).

Hazard Curve

Development of the hazard curve for Building B is described in the PACT Beta Test Overview Report, BD-3.7.13.

1.1.4 Loss Predictions for Baseline Building using Results of Nonlinear Dynamic Analyses

Loss predictions for the baseline building were completed using the nonlinear dynamic analysis method and the results for these baseline analyses are documented in this section. These results are used as the basis for comparison for the simplified analysis method in Section 1.1.5, the extensive sensitivity analyses in Section 1.1.6, and the PEER Benchmark study results in Section 1.1.7.

In completing the baseline analysis, the ATC-58 nonlinear dynamic analysis method was exactly followed, with the following assumptions.

- The Modeling Dispersion (β_m) was taken as 0.35. This is based on Equation 5-1 of ATC-58 Volume 1, using values of $\beta_c = \beta_q = 0.25$.
- The complete set of fragilities was included, as described in the previous Section 1.1.2.
- The baseline model results are based on the average value from 20 runs (each with a different seed value), each utilizing 2000 realizations.

The baseline analysis results are presented in Table 1-6, Table 1-7, and Figure 1-5. Table 1-6 shows the expected annual (EA) results, including both the mean value (the mean of the 20 analyses run) and the coefficient of variation in the results (i.e. the c.o.v. between the 20 analyses run). Table 1-7 and Figure 1-5 show the expected results for each of the eight intensity levels.

Table 1-6 Predictions for the Baseline Building (Expected Annual Values)

EA Values	Cost	Downtime	Fatalities	Injuries	Collapse	Red Tag
Mean	$80,113	2.6	0.0841	0.01017	0.001105	0.004083
COV	1.7%	1.1%	7.5%	7.3%	3.8%	2.6%

Table 1-7 Predictions for the Baseline Building (Expected Values for Each Intensity Level)

Intensity	$Sa(T_1)$ [g]	Expected Loss	Expected Loss as Percentage of Building Cost	Probability of Collapse	Probability of Red Tagging
1	0.16	$849,378	4%	0%	3%
2	0.39	$2,433,778	11%	4%	15%
3	0.63	$7,524,134	35%	13%	53%
4	0.84	$17,042,405	79%	25%	93%
5	1.07	$17,417,353	81%	37%	96%
6	1.30	$18,917,433	88%	48%	99%
7	1.53	$20,355,292	94%	57%	100%
8	1.76	$20,997,973	97%	65%	100%

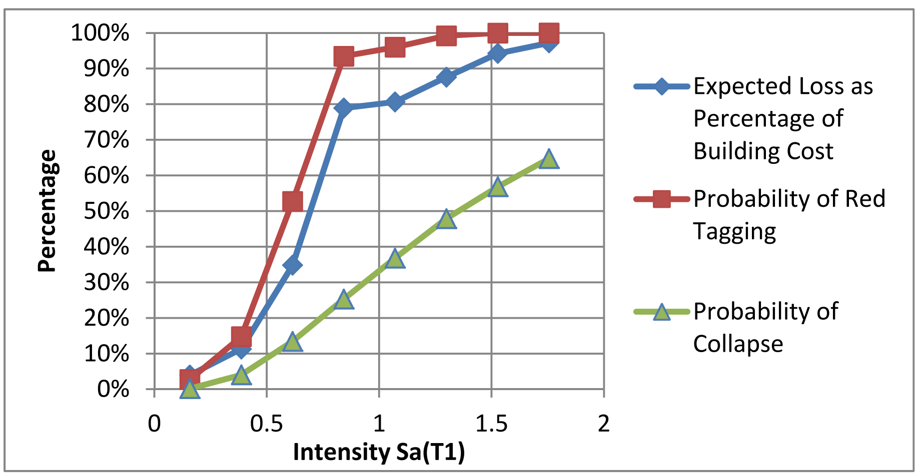


Figure 1-5 Cumulative Collapse and Residual Drift Distribution from Structural Analysis

To put the above intensity levels in perspective, intensity level five is slightly larger than the 2% in 50 year ground motion intensity for this example site (resulting in expected loss of 81% of the building value) and intensity level three is slightly larger than the 10% in 50 year ground motion intensity (resulting in expected loss of 35% of the building value).

In the above downtime results, the repair time is based on an assumption of parallel tasks (for a mean estimate of 2.6 closure days per year); a serial task assumption would result in an estimate of 4.8 closure days per year).

1.1.5 Loss Predictions for Baseline Building using the Simplified Analysis Method

Loss predictions for the baseline building were also completed using the simplified analysis method, in order to compare the loss predictions to those from nonlinear analysis. The ATC-58 simplified analysis method was followed, with the exception of the following modifications and assumptions:

- A linear force distribution was used for pushover instead of using the force distribution Equation 5-8 of the ATC-58 Methodology. This modification is expected to have little effect on the results.
- A fully linear model of the building was not available, so to estimate the interstory drift demands, a slightly different approach was utilized. First, the elastic deflected shape of the building was predicted using a pushover to 1" roof displacement. The target roof displacement demands for each intensity level were then computed using the ASCE 41-06 coefficient method (ASCE-SEI 2006) and then the elastic drifts were estimated for each intensity level using simple linear scaling.
- The median collapse intensity and collapse dispersion were taken to be the same as those computed from nonlinear structural analysis. This kind of collapse capacity data would not normally be available when performing a linear analysis, but it was used in order to make an unbiased evaluation of the demand parameters obtained from the simplified analysis method.

Table 1-8 and Table 1-9 summarize the results from the simplified analysis method side-by-side with the results obtained using the nonlinear dynamic analysis results. Table 1-8 displays the annualized results which show that the simplified method predictions are exceptionally similar to the predictions for the full nonlinear dynamic analysis results (e.g. only a 3% difference for expected annual loss). Table 1-9 extends this comparison by presenting results for each of the eight individual intensity levels; this shows less similarity in predictions between the nonlinear and simplified methods and suggests that the close comparison of Table 1-8 may be partially due to compensating errors between responses at various intensity levels.

A more extensive set of tables and figures in provided in the Appendix Section 1.1.8 (Table 1-43 through Table 1-46 and Figure 1-41 through Figure 1-44) to provide more additional detailed comparisons of the 10th, 50th, and 90th percentiles of the predictions. This set of tables and figures included these comparisons for losses, repair times, injuries, and casualties.

Table 1-8 Expected Annual Losses – Comparison of the Non-Linear and Simplified Linear Analysis Methods

Analysis Method	Cost	Downtime	Fatalities	Injuries	Collapse	Red Tag
Non-Linear (Baseline)	$80,113	2.58	0.08406	0.010165	0.001105	0.004083
Simplified Linear	$82,876	2.79	0.08203	0.009167	0.001092	0.003945
Relative Change	3%	8%	-2%	-10%	-1%	-3%

Table 1-9 Expected Results for Each Intensity Level – Comparison of the Non-Linear and Simplified Linear Analysis Methods

		Expected Loss		Repair Time		Casualties		Injuries		Red Tag Probability	
Int.	Sa(T1) [g]	Non – Linear (BL)	Simplified Linear	Non – Linear (BL)	Simp. Linear	Non – Linear (BL)	Simp. Linear	Non – Linear (BL)	Simp. Linear	Non – Linear (BL)	Simp. Linear
1	0.158	$849,379	$523,750	62.3	60.8	0.06	0.10	0.01	0.01	3%	0%
2	0.387	$2,433,779	$3,411,640	206	254.1	2.85	2.57	0.35	0.29	15%	14%
3	0.615	$7,524,134	$8,167,361	347.4	377.7	10.08	10.51	1.21	1.17	53%	62%
4	0.843	$17,042,406	$11,890,777	396.4	397.2	18.83	19.36	2.26	2.17	93%	92%
5	1.071	$17,417,354	$17,164,110	399.0	399.8	27.32	28.34	3.28	3.15	96%	99%
6	1.299	$18,917,434	$19,103,455	399.9	400.0	35.88	34.84	4.32	3.88	99%	100%
7	1.528	$20,355,292	$20,116,983	400.0	400.0	42.7	42.32	5.27	4.71	100%	100%
8	1.756	$20,997,974	$20,500,879	400.0	400.0	48.15	48.09	5.82	5.36	100%	100%

Table 1-10 documents the factors that were used in the computation of the demand vectors for the simplified method. The Appendix Section 1.1.8 provides a complete comparison between the resulting simplified method demand quantities and the demand quantities from the nonlinear analysis method.

Table 1-10 Simplified Method Factors

Parameter		Intensity Level							
		1	2	3	4	5	6	7	8
$H_{\Delta i}$	IDR_max_4	1.18	1.17	1.15	1.13	1.11	1.09	1.08	1.06
	IDR_max_3	0.97	0.96	0.94	0.93	0.91	0.90	0.89	0.87
	IDR_max_2	1.05	1.04	1.02	1.01	0.99	0.97	0.96	0.94
	IDR_max_1	1.51	1.48	1.46	1.44	1.41	1.39	1.37	1.35
H_{ai}	PFA_5 (g)	1.34	1.18	1.04	0.92	0.81	0.72	0.63	0.56
	PFA_4 (g)	1.32	1.17	1.03	0.91	0.80	0.71	0.63	0.55
	PFA_3 (g)	1.31	1.16	1.02	0.90	0.80	0.70	0.62	0.55
	PFA_2 (g)	1.30	1.15	1.01	0.89	0.79	0.70	0.61	0.54
	PGA (g)	1.34	1.18	1.04	0.92	0.81	0.72	0.63	0.56

1.1.6 Results of Sensitivity Studies

A wide variety of sensitivity studies were conducted to test the effects of various input parameters on the PACT predictions. This was done to test the stability of the PACT predictions (i.e. to see how sensitive the results are to various input values and decisions), to develop information for best-practices for PACT input decisions (e.g. how many stripes to use, how many realizations to use, etc.), and to more extensively debug the PACT software.

Studies of sensitivity were completed to look at the following input parameters and decision points:

- Sensitivity to Number of Realizations
- Sensitivity to Correlation of Fragilities
- Sensitivity to the Inclusion of Anchorage Fragilities
- Sensitivity to Seismic Hazard Curve
- Sensitivity to Alternate Population Model
- Sensitivity to Alternate Collapse Mode
- Sensitivity to Collapse Capacity Median
- Sensitivity to Collapse Capacity Dispersion
- Sensitivity to Number of Stripes
- Sensitivity to Number of Demand Vectors
- Sensitivity to Modeling Dispersion (β_m) Value
- Sensitivity to the Median Residual Drift Capacity
- Sensitivity to Dispersion of the Residual Drift Capacity

- Sensitivity to Using an Alternate Calculation Method of Computing Residual Drifts
- Sensitivity to Which Fragilities are Included in the Assessment
- Sensitivity to Partition Fragility Quantity Determination

The results presented in this section are all based on the average of three PACT runs (each run with a difference seed number), with 2000 realizations per run, unless otherwise specified.

Sensitivity to the Number of Realizations

The analyses were run with between 100 and 10,000 realizations, to assess how the number of realizations affects the PACT predictions. The optimal number of realizations will depend heavily on the size of the building and PACT model, so these results are only representative of the four-story building used in this example.

Table 1-11 shows the effects on the run time, memory usage, and time to load the PACT output results. Table 1-12 and Figure 1-6 then show the coefficient of variation (C.O.V.) in the results, which explains the stability of the predictions (i.e. this is the variability in the predictions using five runs with different seed numbers). This shows that using a larger number of realizations reduces the coefficient of variation (as expected), but that there are diminishing returns for more than 3,500 realizations. This also shows that the use of more than 7,500 realizations is not possible using a computer with 8GB of RAM, because of the inability to load the results page from PACT.

Note that the results of this section are based on using fully correlated fragilities, and the findings would differ if the fragilities were uncorrelated.

Table 1-11 Number of Realizations Used, Run Time, RAM Used, and Time to Load Results

Number of Realizations	Run Time (sec)	RAM Used (MB)	Loading Results Page (sec)
100	1	151	16
500	6	475	23
1,000	13	850	30
1,500	17	1,260	37
2,000 (BL)	23	1,700	47
2,500	32	2,000	57
3,500	41	2,700	75
5,000	60	4,000	100
7,500	95	5,800	151
10,000	1,860	7,000	--

Table 1-12 C.O.V. of E.A. Values with Relation to the Number of Realizations Used

Number of Realizations	Cost	Downtime	Fatalities	Injuries	Collapse	Red Tag
100	8.3%	4.5%	40.1%	39.9%	18.1%	7.2%
500	7.9%	4.6%	11.6%	10.0%	12.9%	6.3%
1,000	3.0%	2.0%	11.0%	9.8%	5.5%	4.6%
1,500	3.1%	2.0%	11.5%	10.8%	9.4%	4.5%
2,000 (BL)	2.4%	1.4%	9.4%	9.4%	5.0%	3.9%
2,500	1.9%	1.1%	9.2%	8.8%	1.1%	1.3%
3,500	1.6%	0.8%	7.2%	6.9%	5.1%	1.7%
5,000	1.0%	0.5%	6.9%	7.0%	2.5%	1.2%
7,500	0.6%	0.4%	2.6%	2.2%	1.6%	0.8%
10,000	-	-	-	-	-	-

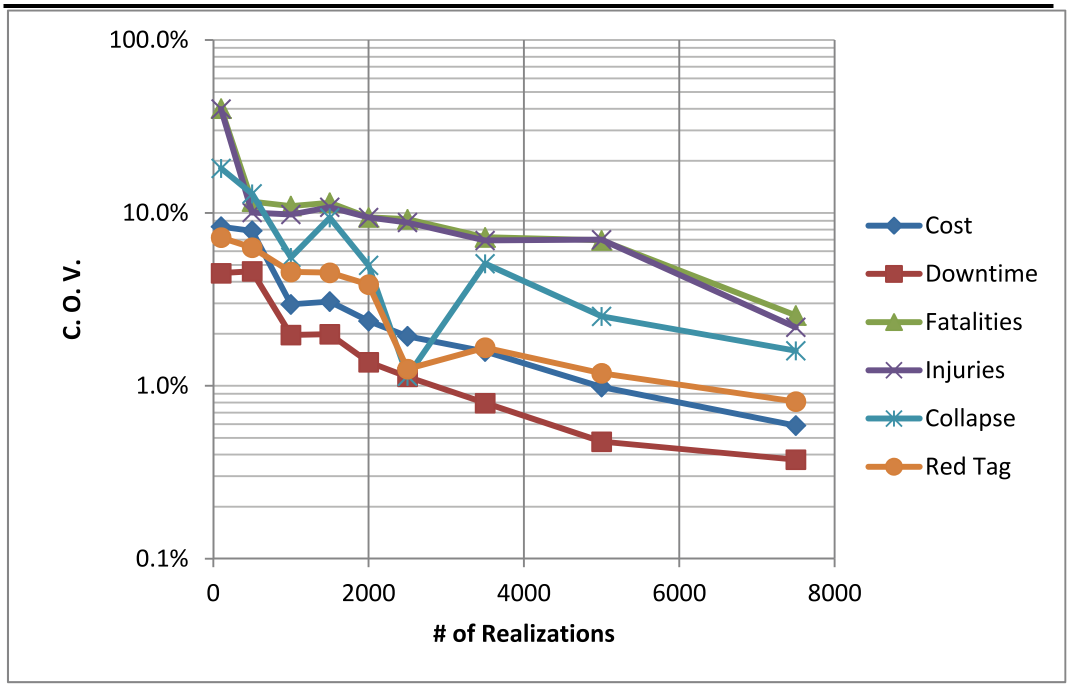


Figure 1-6 Variability in the Expected Annual Prediction (Coefficient of Variation Values) as a Function of the Number of Realizations.

Sensitivity to the Correlation of Fragilities

Table 1-13 and Table 1-14 shows the effects of using uncorrelated fragility functions rather than correlated functions (which were used for the baseline model). Table 1-13 shows the expected annual predictions and Table 1-14 shows the more detailed percentile values for each of the eight intensity levels. The uncorrelated model results are based on an average of five runs, each with 500 realization; this number of realizations the upper limit for running this PACT model using a computer system with 8GB of RAM.

The comparisons in Table 1-13 and Table 1-14 shows that the correlation assumption have minimal impact on the predictions of losses, but have a meaningful impact on the rate of red tagging (20% change) and a measurable impact on the fatality and injury rates (11% change).

Table 1-13 Sensitivity to Fragility Correlations

Fragilities	Cost	Downtime	Fatalities	Injuries	Collapse	Red Tag
Correlated (BL)	$80,114	2.6	0.0841	0.0102	0.0011	0.0041
Uncorrelated	$81,042	2.4	0.0931	0.0113	0.0012	0.0033
Relative Change	1%	-6%	11%	11%	6%	-20%

Table 1-14 Sensitivity to Fragility Correlations - Results by Intensity, including Mean, 10th Percentile, and 90th Percentile

Intensity	Variable	Mean		10th Percentile		90th Percentile	
		Corr. (BL)	Uncor.	Corr. (BL)	Uncor.	Corr. (BL)	Uncor.
1	Repair Cost	$849,379	$828,524	$230,230	$251,378	$768,824	$745,836
	Repair Time (days)	62.3	61.4	10.6	10.5	46.4	36.8
	# of Fatalities	0.1	0.2	0.0	0.0	0.0	0.0
	# of Injuries	0.0	0.0	0.0	0.0	0.0	0.0
2	Repair Cost	$2,433,779	$2,522,418	$801,065	$874,430	$2,576,375	$2,457,895
	Repair Time (days)	206.0	208.9	41.3	40.9	141.4	119.5
	# of Fatalities	2.9	3.3	0.0	0.0	1.7	2.1
	# of Injuries	0.4	0.4	0.0	0.0	0.4	0.4
3	Repair Cost	$7,524,134	$7,642,654	$1,803,849	$1,873,738	$20,962,151	$20,962,138
	Repair Time (days)	347.4	349.7	86.9	88.3	396.2	396.4
	# of Fatalities	10.1	10.8	0.0	0.0	7.8	5.1
	# of Injuries	1.2	1.3	0.0	0.0	0.9	0.9
4	Repair Cost	$17,042,406	$17,185,881	$3,621,767	$3,601,111	$20,987,076	$20,987,229
	Repair Time (days)	396.4	397.0	168.5	160.5	398.7	398.7
	# of Fatalities	18.8	19.7	0.0	0.0	16.7	17.1
	# of Injuries	2.3	2.4	0.0	0.0	5.2	3.1
5	Repair Cost	$17,417,354	$17,381,767	$4,159,697	$4,196,889	$20,987,406	$20,987,282
	Repair Time (days)	399.0	399.2	182.8	175.3	398.7	398.7
	# of Fatalities	27.3	25.1	0.0	0.0	122.5	141.7
	# of Injuries	3.3	3.0	0.0	0.0	14.7	16.0
6	Repair Cost	$18,917,434	$19,003,954	$5,362,910	$5,353,333	$20,988,586	$20,988,541
	Repair Time (days)	400.0	400.0	238.5	230.3	398.9	398.9
	# of Fatalities	35.9	37.0	0.0	0.0	168.8	167.7
	# of Injuries	4.3	4.5	0.0	0.0	19.3	18.5
7	Repair Cost	$20,355,292	$20,421,843	$20,905,858	$20,906,358	$20,989,540	$20,989,595
	Repair Time (days)	400.0	400.0	390.6	390.7	399.0	399.0
	# of Fatalities	42.7	43.6	0.0	0.0	201.5	194.1
	# of Injuries	5.3	5.4	0.0	0.0	23.0	21.6
8	Repair Cost	$20,997,974	$21,000,000	$20,909,985	$20,909,964	$20,989,998	$20,989,996
	Repair Time (days)	400.0	400.0	391.0	391.0	399.0	399.0
	# of Fatalities	48.2	47.9	0.0	0.0	210.3	214.1
	# of Injuries	5.8	5.8	0.0	0.0	23.7	23.9

Sensitivity to the Inclusion of Anchorage Fragilities

Table 1-15 shows that there is minimal impact on the PACT predictions when the anchorage fragilities are excluded from the assessment (i.e. the Table 1-4 that are labeled as either anchorage or bracing fragilities are excluded from the PACT model).

Table 1-15 Sensitivity to Bracing Fragilities

Fragilities	Cost	Downtime	Fatalities	Injuries	Collapse	Red Tag
All Fragilities (BL)	$80,114	2.58	0.0841	0.0102	0.0011	0.0041
No Anchorage Fragilities	$78,516	2.55	0.0780	0.0097	0.0010	0.0041
Relative Change	-2%	-1%	-7%	-5%	-6%	0%

Sensitivity to the Hazard Curve Used

Table 1-16 and Figure 1-7 compare the USGS and PEER Benchmark (Haselton et al. 2008) hazard curves. This comparison shows that the PEER Benchmark hazard curve includes a much higher frequency of small ground motion levels. The USGS hazard curve was used for the baseline PACT model and the PEER Benchmark hazard curve is used as a comparison point to show the sensitivity to the probabilistic seismic hazard analysis. When the PEER Benchmark curve is used in the assessment, the red extrapolated curve from Figure 1-7 is utilized because the PEER Benchmark hazard analysis did not extend to all ground motion levels of interest for this current study.

Table 1-17 summarizes the effect of using the PEER Benchmark hazard curve instead of the USGS hazard curve. This shows a large change (factor of two) in every PACT prediction, resulting from the more frequent lower-level ground motion predicted in the PEER Benchmark seismic hazard analysis. This comparison (a) shows that the hazard curve can have substantial effect on the PACT predictions, and (b) shows that the difference in hazard curve will be an important consideration when comparing the results of this study to the results of the previous PEER Benchmark study (this comparison is done later in Section 1.1.7).

Table 1-16 USGS and Benchmark Hazard Curves Mean Annual Frequencies of Exceedance (MAFE)

Intensity	Baseline (USGS)	Benchmark	Relative Change
Min	0.1	0.4	300%
1	0.025	0.065	160%
2	0.0047	0.0065	38%
3	0.0016	0.0014	-13%
4	0.00064	0.00038	-41%
5	0.00032	0.00032	0%
6	0.00017	0.00017	0%
7	0.0001	0.0001	0%
8	0.00005	0.00005	0%
Max	0.000033	0.000033	0%

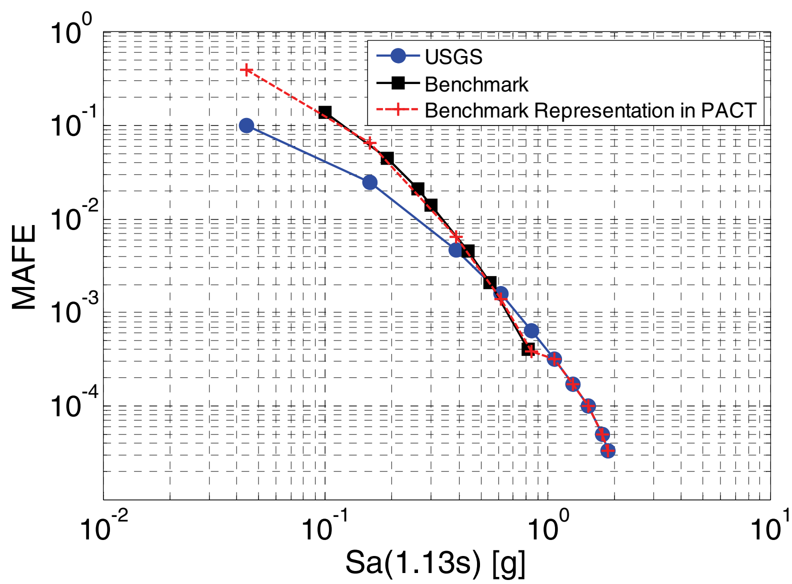


Figure 1-7 Hazard Curves based on USGS and Benchmark calculations.

Table 1-17 Sensitivity to Hazard Curve

Hazard Curve	Cost	Downtime	Fatalities	Injuries	Collapse	Red Tag
USGS (BL)	$80,114	2.58	0.0841	0.0102	0.00111	0.00408
Benchmark	$166,876	5.89	0.1647	0.0196	0.00204	0.00806
Relative Change	108%	128%	96%	93%	85%	97%

Sensitivity to Using an Alternate Population Model

Figure 1-8 shows two alternative population models, showing the occupancy per day for the baseline office model versus the retail model (please note the difference in population scale on the y-axis). Table 1-18 provides the resulting PACT predictions using the two alternative models. As expected, this shows that the occupancy model only affects the rate of fatality and injury, which in these comparisons increase substantially, by approximately 75%.

(a) (b)

Figure 1-8 Building Population models occupancy per day, (a) Retail Model (b) Office Model.

Table 1-18 Sensitivity to Population Model

Population Model	Cost	Downtime	Fatalities	Injuries	Collapse	Red Tag
Office (BL)	$80,114	2.58	0.0841	0.0102	0.00111	0.0041
Retail	$79,333	2.57	0.1480	0.0181	0.00106	0.0041
Relative Change	-1%	0%	76%	78%	-4%	0%

Sensitivity to Alternate Collapse Modes

Figure 1-8 shows two alternative collapse modes, with the associated percentages of floor area subjected to collapse debris for each story of the building. Table 1-18a provides the resulting PACT predictions using the two alternative collapse modes. As expected, this shows that the assumed collapse mode only affects the rate of fatalities and injuries, which in these comparisons decrease substantially, by approximately 45-70%. Table 1-18b extends this comparison by showing a case between the two extreme cases, where there is a 50% chance of full collapse and a 50% change of soft story collapse; this shows a 40-45% reduction in fatalities and injuries as compared with the baseline case.

Table 1-19 Collapse Modes and Percentages of Floor Areas Subject to Collapse Debris

Building Story	Full Collapse (Baseline)	Soft Story Collapse
4	1.0	0.1
3	1.0	0.1
2	1.0	0.1
1	1.0	0.9

Table 1-20 Sensitivity to Collapse Modes – Expected Annual Predictions and Relative Changes from Baseline Model, (a) Baseline Full Collapse versus Soft Story Collapse, (b) Baseline Full Collapse versus a 50% Probability of Each Full and Soft Story Collapses

(a)

Collapse Mode	Cost	Downtime	Fatalities	Injuries	Collapse	Red Tag
Full Collapse (BL)	$80,114	2.58	0.0841	0.0102	0.00111	0.00408
Soft Story	$79,730	2.57	0.0260	0.0056	0.00108	0.00410
Relative Change	-1%	-1%	-68%	-45%	-2%	1%

(b)

Collapse Mode(s)	Cost	Downtime	Fatalities	Injuries	Collapse	Red Tag
Full Collapse (BL)	$80,114	2.58	0.0841	0.0102	0.00111	0.00408
Both (50%-50%)	$79,703	2.57	0.0465	0.006	0.00111	0.00421
Relative Change	-1%	0%	-45%	-41%	0%	3%

Sensitivity to Collapse Capacity Median

Table 1-21 and Figure 1-9 show the effects of changing the median collapse capacity of the building. The baseline collapse capacity distribution has a median value of Sa(1.13s) = 1.35g and a logarithmic standard deviation of 0.5. This sensitivity study assesses the effects of modifying the median collapse capacity by 0.5x, 0.75x, 1.5x, and 2x. The results show substantial changes to all of the building performance predictions, with especially large changes to the annual rates of collapse, fatalities, and injuries (as expected).

Table 1-21 Sensitivity to the Median Collapse Capacity, Relative Changes from Baseline

Median Collapse Capacity	Cost	Downtime	Fatalities	Injuries	Collapse	Red Tag
0.68g	72%	36%	305%	277%	295%	59%
1.01g	20%	10%	86%	79%	89%	16%
1.35g (BL)	0%	0%	0%	0%	0%	0%
2.03g	-13%	-7%	-67%	-60%	-68%	-9%
2.70g	-16%	-8%	-84%	-74%	-85%	-42%

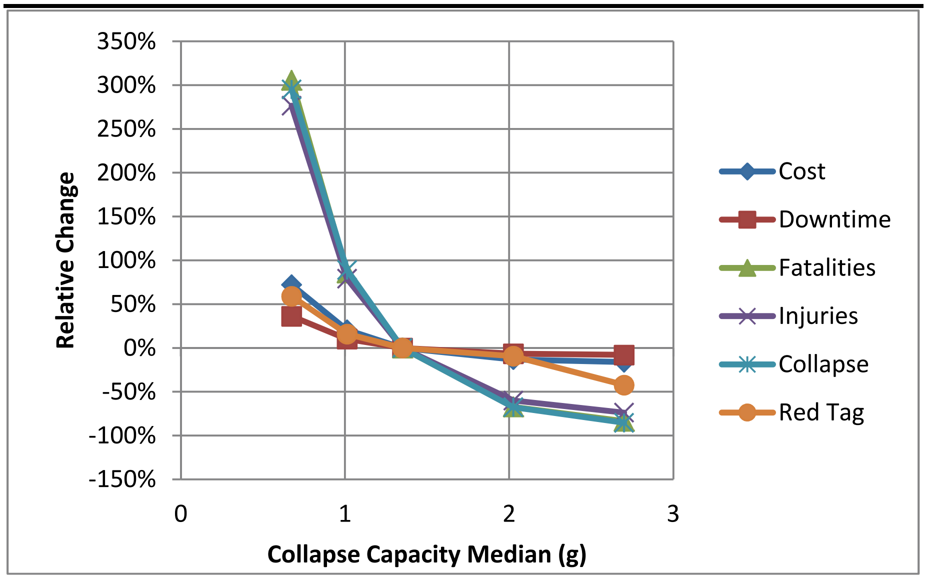


Figure 1-9 Sensitivity to the Median Collapse Capacity, Relative Changes from Baseline

Sensitivity to Collapse Capacity Median Dispersion

Table 1-22 and Figure 1-10 show the effects of changing the dispersion in the building collapse capacity. The baseline dispersion value is a logarithmic standard deviation of 0.5. This sensitivity study assesses the effects of modifying this value of dispersion from 0.0 to 0.9. The results show modest changes to the annualized cost and the rates of downtime and red tagging. However, the results show substantial changes to the annual rates of collapse, fatalities, and injuries (as expected).

Table 1-22 Sensitivity to the Dispersion in Collapse Capacity, Relative Changes from Baseline

Dispersion in Collapse Capacity	Cost	Downtime	Fatalities	Injuries	Collapse	Red Tag
0.01	-15%	-7%	-53%	-48%	-54%	-11%
0.1	-15%	-7%	-52%	-48%	-55%	-10%
0.2	-12%	-6%	-46%	-41%	-49%	-9%
0.3	-10%	-5%	-40%	-38%	-37%	-9%
0.4	-6%	-3%	-23%	-23%	-23%	-8%
0.5 (BL)	0%	0%	0%	0%	0%	0%
0.6	5%	3%	26%	23%	20%	4%
0.7	14%	7%	66%	60%	50%	9%
0.8	22%	11%	101%	94%	83%	17%
0.9	33%	23%	147%	135%	113%	25%

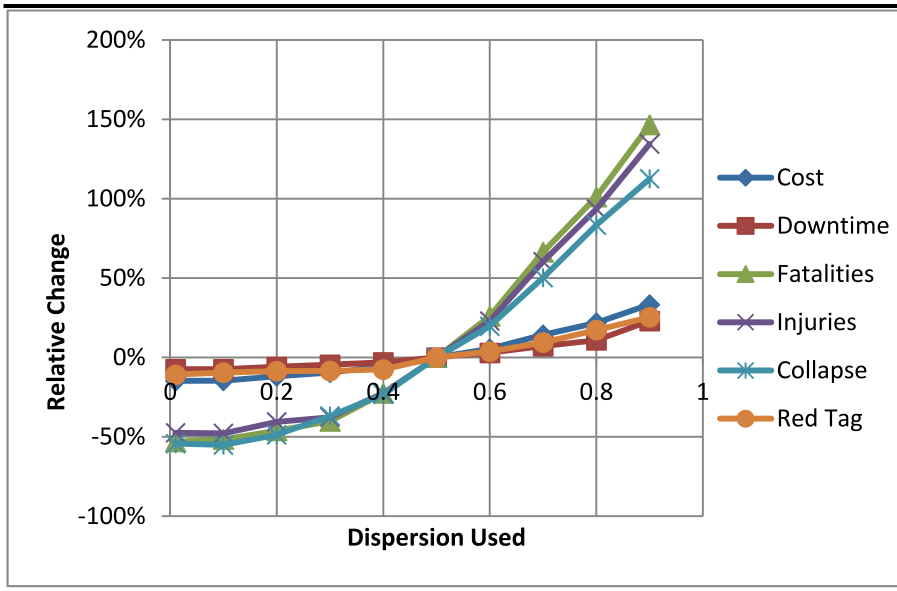


Figure 1-10 Sensitivity to the Dispersion in Collapse Capacity, Relative Changes from Baseline

Sensitivity to Number of Stripes

Table 1-23 shows the effects of changing the number of stripes used in the performance assessment. The baseline model utilized eight stripes and the sensitivity study included looking at various options for the use of six, four, or three stripes. Additionally, several different options were considered for the four- and three-stripe cases; in most cases individual stripes were selected from the baseline set of eight stripes, but in one case, the average of subsequent stripes was used for the assessment.

The Table 1-23 results can be summarized as follows (as compared with the baseline case of eight stripes):

- The use of six stripes results in similar predictions for all response metrics.
- When using four stripes, selecting stripes 1, 2, 3, and 4 results in similar predictions for all response metrics.
- When using four stripes, the approach of taking four averaged stripes results in a similar prediction of the annual cost, but larger predictions for most of the other response metrics.
- When using either three or four stripes, the predictions are highly sensitive to the placement of the first stripe. When the stripe #1 is used as the lowest stripe, the predictions are much larger for all response metrics. When the stripe #2 is used as the lowest stripe, the predictions are much smaller for all response metrics. This comes from the fact that stripe #1 has a much higher annual rate of occurrence as compared with stripe #2 (from the results of the ground motion hazard analysis). This suggests that it is highly important to place the stripes to carefully represent these frequent levels of ground motion in the building performance assessment.

Table 1-23 Sensitivity to the Number of Stripes

Number of Stripes	Cost	Downtime	Fatalities	Injuries	Collapse	Red Tag
8 (BL)	$80,114	2.6	0.0841	0.0102	0.00111	0.00408
6 (1,2,3,4,5,6)	$78,362	2.6	0.0852	0.0102	0.00107	0.00392
4 (1,2,3,4)	$76,795	2.5	0.0759	0.0092	0.00087	0.00349
4 (Averaged) 1+2,3+4,5+6,7+8	$80,073	2.6	0.1433	0.0172	0.00174	0.00572
4 (2,4,5,7)	$55,914	1.3	0.0663	0.0081	0.00077	0.00271
4 (1,3,6,8)	$131,544	3.6	0.1612	0.0194	0.00207	0.00773
3 (2,5,8)	$56,859	1.4	0.0920	0.0111	0.00105	0.00269
3 (1,4,7)	$242,973	5.3	0.2702	0.0331	0.00334	0.01227

Sensitivity to Number of Demand Vectors

The eleven ground motions selected for each intensity level were ranked according to how well they fit the target spectrum over the period range of interest. To study the sensitivity to the number of demand vectors, the number was reduced from eleven systematically down to five and up to 20 (each time retaining the motions that best fit the target spectrum). Table 1-24 summarizes the results of changing the number of demand vectors. The results show that the accuracy of the predictions was not significantly affected when the number of demand vectors was reduced, even down to five demand vectors. The stability in the predictions likely comes from selecting the ground motions to provide a close fit to the target spectrum.

Table 1-25 also shows the coefficients of variation for the various predictions; these are rough approximate values based on the variability in the predictions between five analysis runs, each with 2000 realizations. These results show that the number of demand vectors also does not have a substantial effect on the stability of the performance predictions, even down to five demand vectors. This prediction stability is also likely a result of selecting the ground motions that provided a close fit to the target spectrum.

One important caveat is that the above sensitivity study was computed using a constant assumed collapse fragility. However, the intensity level for median collapse and the collapse dispersion could not have been accurately determined from only a few ground motions at each intensity level. Therefore, it may be justifiable to use only a few of the best-fitting ground motions to generate demand vectors for PACT, but more may be needed to accurately estimate the collapse fragility.

Table 1-24 Sensitivity to the Number of Demand Vectors - Relative Change in the Median Predictions as Compared with the Baseline Case

Number of Demand Vectors	Cost	Downtime	Fatalities	Injuries	Collapse	Red Tag
5	4%	3%	-4%	-5%	-4%	-1%
7	-1%	0%	5%	5%	-2%	-7%
9	-4%	-1%	5%	6%	-2%	-3%
11	0%	0%	0%	0%	0%	0%
20	-7%	-5%	5%	7%	-2%	1%

Table 1-25 Sensitivity to the Number of Demand Vectors – Coefficients of Variation in Predictions

Number of Demand Vectors	Cost	Downtime	Fatalities	Injuries	Collapse	Red Tag
5	1%	0%	10%	10%	5%	1%
7	3%	2%	9%	7%	6%	2%
9	2%	5%	8%	8%	8%	3%
11	2%	1%	9%	9%	5%	4%
20	2%	1%	9%	9%	5%	3%

Sensitivity to Modeling Dispersion (β_m) Value

Table 1-26, Table 1-27, and Figure 1-11 shows the sensitivity to the value of modeling dispersion used in the performance assessment. These results show that there are minimal impacts on most of the response metrics, but that there are important impacts on the annual rate of injuries and red tagging.

Table 1-28 extends this comparison to show more detail regarding the effect that the modeling dispersion has on the resulting predictions for each of the eight levels of ground motion intensity. This table provides the results for the mean prediction, the 10th percentile, and the 90th percentile.

Table 1-26 Sensitivity to the Modeling Dispersion (β_m) – Expected Annual Values

β_m	Cost	Downtime	Fatalities	Injuries	Collapse	Red Tag
0.0	$74,300	2.4	0.0817	0.0092	0.00109	0.00272
0.14	$75,067	2.4	0.0779	0.0088	0.00105	0.00280
0.27	$78,050	2.5	0.0778	0.0091	0.00108	0.00348
0.35 (BL)	$80,113	2.6	0.0841	0.0102	0.00111	0.00408
0.47	$86,079	2.8	0.0870	0.0115	0.00114	0.00541
0.5	$86,916	2.8	0.0917	0.0129	0.00111	0.00579

Table 1-27 Sensitivity to the Modeling Dispersion (β_m) – Relative Changes from Baseline

β_m	Cost	Downtime	Fatalities	Injuries	Collapse	Red Tag
0.0	-7%	-8%	-3%	-9%	-1%	-33%
0.14	-6%	-7%	-7%	-13%	-5%	-31%
0.27	-3%	-3%	-7%	-10%	-2%	-15%
0.35 (BL)	0%	0%	0%	0%	0%	0%
0.47	7%	7%	3%	13%	4%	32%
0.5	8%	9%	9%	27%	1%	42%

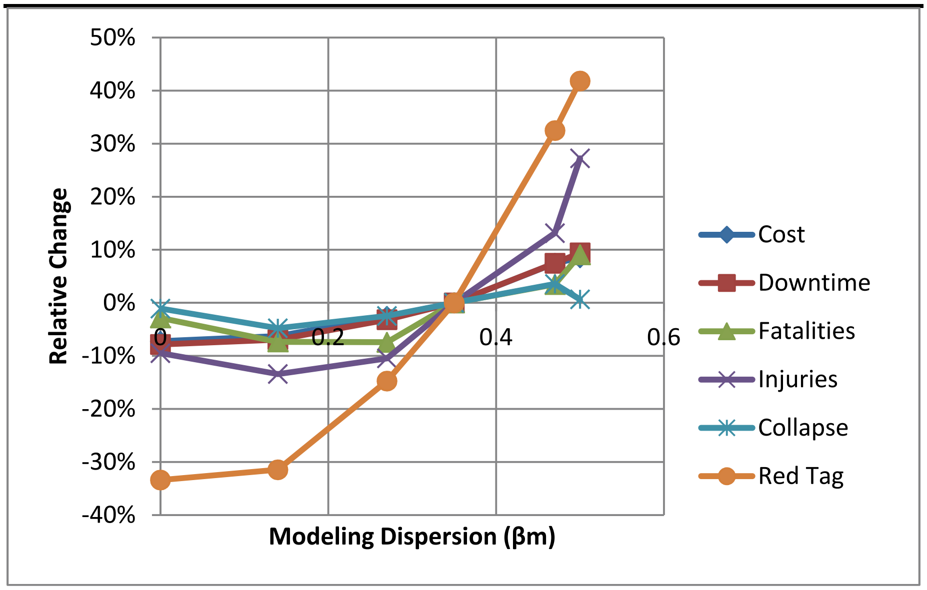


Figure 1-11 Sensitivity to the Modeling Dispersion (βm), Relative Changes from Baseline

Table 1-28 Sensitivity to the Modeling Dispersion (βm) – Predictions for Each of the Eight Levels of Intensity, Showing the (a) Mean, (b) 10th Percentile, and (c) 90th Percentile of the Predictions.

(a)

		Mean					
Int.	**Variable**	**βm = 0.0**	**βm = 0.14**	**βm = 0.24**	**βm = 0.35 (Baseline)**	**βm = 0.47**	**βm = 0.50**
1	Repair Cost	$752,937	$804,628	$856,730	$849,379	$890,086	$856,730
	Repair Time (d)	53.6	55.2	59.4	62.3	69.3	59.4
	# of Fatalities	0.1	0.1	0.1	0.1	0.0	0.1
	# of Injuries	0.0	0.0	0.0	0.0	0.0	0.0
2	Repair Cost	$2,092,791	$2,091,740	$2,252,499	$2,433,779	$2,805,530	$2,252,499
	Repair Time (d)	184.4	187.6	196.2	206.0	221.1	196.2
	# of Fatalities	2.5	2.2	2.3	2.9	3.2	2.3
	# of Injuries	0.3	0.3	0.3	0.4	0.4	0.3
3	Repair Cost	$7,358,816	$7,347,344	$7,398,565	$7,524,134	$7,976,723	$7,398,565
	Repair Time (d)	345.0	345.9	346.4	347.4	352.4	346.4
	# of Fatalities	9.1	10.7	9.5	10.1	9.9	9.5
	# of Injuries	1.0	1.2	1.1	1.2	1.3	1.1
4	Repair Cost	$17,461,478	$17,297,358	$17,150,487	$17,042,406	$16,946,755	$17,150,487
	Repair Time (d)	398.0	397.6	397.2	396.4	396.1	397.2
	# of Fatalities	19.1	17.8	18.5	18.8	18.6	18.5
	# of Injuries	2.2	2.0	2.2	2.3	2.4	2.2
5	Repair Cost	$17,659,604	$17,517,511	$17,645,497	$17,417,354	$17,332,218	$17,645,497
	Repair Time (d)	399.8	399.5	399.5	399.0	398.6	399.5
	# of Fatalities	28.6	29.5	29.6	27.3	28.5	29.6
	# of Injuries	3.3	3.4	3.4	3.3	3.5	3.4
6	Repair Cost	$18,970,180	$19,162,081	$19,107,922	$18,917,434	$18,745,312	$19,107,922
	Repair Time (d)	400.0	400.0	400.0	400.0	399.9	400.0
	# of Fatalities	34.7	36.1	37.4	35.9	36.7	37.4
	# of Injuries	4.0	4.2	4.4	4.3	4.6	4.4
7	Repair Cost	$20,540,576	$20,481,652	$20,476,811	$20,355,292	$20,327,022	$20,476,811
	Repair Time (d)	400.0	400.0	400.0	400.0	400.0	400.0
	# of Fatalities	41.5	41.6	42.0	42.7	43.5	42.0
	# of Injuries	4.9	5.0	5.1	5.3	5.5	5.1
8	Repair Cost	$21,000,000	$21,000,000	$21,000,000	$20,997,974	$20,976,632	$21,000,000
	Repair Time (d)	400.0	400.0	400.0	400.0	400.0	400.0
	# of Fatalities	47.5	47.9	47.7	48.2	47.1	47.7
	# of Injuries	5.7	5.7	5.7	5.8	5.8	5.7

(b)

Int.	Variable	10th Percentile βm = 0.0	βm = 0.14	βm = 0.24	βm = 0.35 (Baseline)	βm = 0.47	βm = 0.50
1	Repair Cost	$246,117	$241,396	$232,954	$230,230	$217,211	$218,393
	Repair Time (d)	10.9	10.7	10.7	10.6	10.5	10.1
	# of Fatalities	0	0	0	0	0	0
	# of Injuries	0	0	0	0	0	0
2	Repair Cost	$860,649	$844,721	$817,983	$801,065	$766,594	$772,232
	Repair Time (d)	45.4	43.9	42.5	41.3	40.9	41.2
	# of Fatalities	0	0	0	0	0	0
	# of Injuries	0	0	0	0	0	0
3	Repair Cost	$1,898,172	$1,884,727	$1,835,270	$1,803,849	$1,751,831	$1,772,425
	Repair Time (d)	92.4	92.5	90.0	86.9	89.2	86.8
	# of Fatalities	0	0	0	0	0	0
	# of Injuries	0	0	0	0	0	0
4	Repair Cost	$3,575,549	$3,631,455	$3,589,776	$3,621,767	$3,686,883	$3,607,320
	Repair Time (d)	169.1	166.9	166.9	168.5	167.2	165.6
	# of Fatalities	0	0	0	0	0	0
	# of Injuries	0	0	0	0	0	0
5	Repair Cost	$4,148,770	$4,179,001	$4,166,215	$4,159,697	$4,147,348	$4,149,583
	Repair Time (d)	185.4	184.9	185.2	182.8	181.0	185.1
	# of Fatalities	0	0	0	0	0	0
	# of Injuries	0	0	0	0	0	0
6	Repair Cost	$5,362,037	$5,302,137	$5,325,584	$5,362,910	$5,196,892	$5,252,279
	Repair Time (d)	239.0	250.9	240.4	238.5	231.2	236.2
	# of Fatalities	0	0	0	0	0	0
	# of Injuries	0	0	0	0	0	0
7	Repair Cost	$20,906,815	$20,906,670	$20,906,526	$20,905,858	$20,905,759	$20,905,495
	Repair Time (d)	390.7	390.7	390.7	390.6	390.6	390.6
	# of Fatalities	0	0	0	0	0	0
	# of Injuries	0	0	0	0	0	0
8	Repair Cost	$20,910,000	$20,910,000	$20,910,000	$20,909,985	$20,909,940	$20,909,820
	Repair Time (d)	391.0	391.0	391.0	391.0	391.0	391.0
	# of Fatalities	0	0	0	0	0	0
	# of Injuries	0	0	0	0	0	0

(c)

Int.	Variable	90th Percentile βm = 0.0	βm = 0.14	βm = 0.24	βm = 0.35 (Baseline)	βm = 0.47	βm = 0.50
1	Repair Cost	$593,594	$634,513	$697,494	$768,824	$953,883	$997,669
	Repair Time (d)	36.8	37.9	41.3	46.4	56.3	59.2
	# of Fatalities	0	0	0	0	0	0
	# of Injuries	0	0	0	0	0	0
2	Repair Cost	$2,047,252	$2,130,811	$2,404,729	$2,576,375	$3,048,148	$3,128,746
	Repair Time (d)	115.6	120.3	129.0	141.4	158.7	166.4
	# of Fatalities	0.4	4.6	4.1	1.7	1.8	1.5
	# of Injuries	0.2	0.5	0.5	0.4	0.6	0.6
3	Repair Cost	$20,960,442	$20,962,937	$20,961,919	$20,962,151	$20,963,824	$20,964,140
	Repair Time (d)	395.9	396.1	396.1	396.2	396.3	396.3
	# of Fatalities	7.8	8.0	7.9	7.8	5.4	7.8
	# of Injuries	0.8	0.8	0.9	0.9	0.9	1.0
4	Repair Cost	$20,987,179	$20,987,317	$20,986,949	$20,987,076	$20,987,082	$20,986,924
	Repair Time (d)	398.7	398.7	398.7	398.7	398.7	398.7
	# of Fatalities	17.2	18.7	18.6	16.7	16.6	40.3
	# of Injuries	2.3	2.9	4.3	5.2	7.3	9.3
5	Repair Cost	$20,987,528	$20,987,414	$20,987,336	$20,987,406	$20,987,185	$20,987,266
	Repair Time (d)	398.7	398.7	398.7	398.7	398.7	398.7
	# of Fatalities	115.9	133.3	116.3	122.5	127.6	124.3
	# of Injuries	13.2	15.2	14.0	14.7	15.2	16.0
6	Repair Cost	$20,988,640	$20,988,620	$20,988,590	$20,988,586	$20,988,441	$20,988,365
	Repair Time (d)	398.9	398.9	398.9	398.9	398.8	398.8
	# of Fatalities	163.9	172.4	177.9	168.8	160.4	176.0
	# of Injuries	18.5	19.3	19.9	19.3	18.6	20.2
7	Repair Cost	$20,989,646	$20,989,630	$20,989,614	$20,989,540	$20,989,529	$20,989,499
	Repair Time (d)	399.0	399.0	399.0	399.0	399.0	399.0
	# of Fatalities	198.2	193.1	197.4	201.5	183.4	188.2
	# of Injuries	22.1	21.7	22.2	23.0	21.4	21.5
8	Repair Cost	$20,990,000	$20,990,000	$20,990,000	$20,989,998	$20,989,993	$20,989,980
	Repair Time (d)	399.0	399.0	399.0	399.0	399.0	399.0
	# of Fatalities	224.4	218.7	210.6	210.3	212.5	202.9
	# of Injuries	25.1	24.4	23.6	23.7	24.0	23.0

Sensitivity to the Median Residual Drift Capacity

Table 1-29 and Figure 1-12 shows the effects of changing the median residual drift capacity from the baseline value of 0.01 (1% residual interstory drift). This shows that changes to the median residual drift capacity can have large effects on the predictions, especially when the residual drift capacity is assumed to be a small value (e.g. 0.005).

Table 1-29 Sensitivity to the Median Residual Drift Capacity, Relative Changes from Baseline

Median Capacity	Cost	Downtime	Red Tag
0.005	49%	25%	38%
0.01 (BL)	0%	0%	0%
0.02	-15%	-7%	-6%
0.05	-24%	-11%	-11%
Infinite	-27%	-13%	-10%

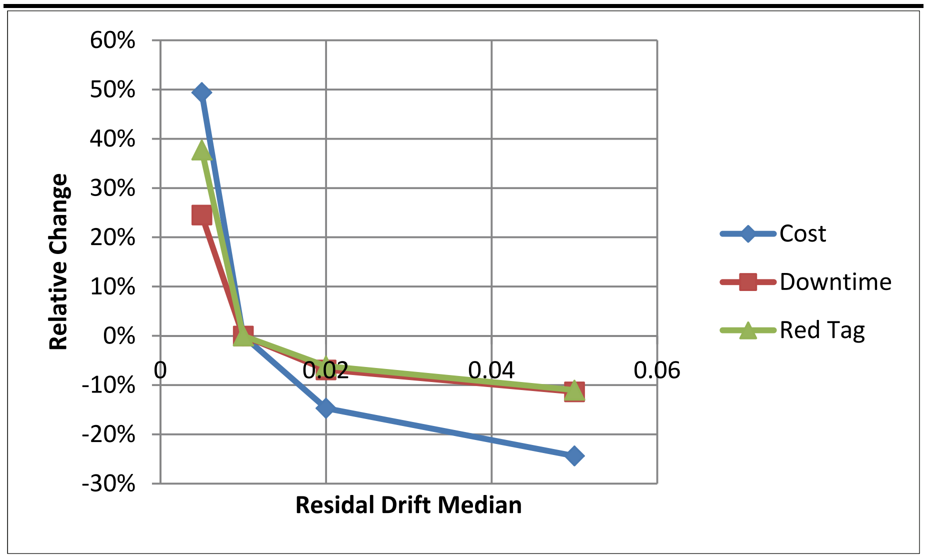


Figure 1-12 Sensitivity to the Median Residual Drift Capacity, Relative Changes from Baseline

Sensitivity to the Dispersion in the Residual Drift Capacity

Table 1-30 and Figure 1-13 shows the effects of changing the residual drift capacity dispersion from the baseline value of 0.30. This shows a much smaller effect as compared with changes to the median capacity values, but does show that large increases in the dispersion value (e.g. values above 0.7) do result in meaningful changes to the performance predictions.

Table 1-30 Sensitivity to the Dispersion in the Residual Drift Capacity, Relative Changes from Baseline

Dispersion in Capacity	Cost	Downtime	Red Tag
0.0	-1%	-1%	-1%
0.1	-3%	-2%	-3%
0.2	-2%	-1%	-1%
0.3 (BL)	0%	0%	0%
0.4	2%	1%	1%
0.5	8%	4%	7%
0.6	8%	4%	8%
0.7	15%	7%	12%
0.8	22%	11%	19%
0.9	26%	13%	22%

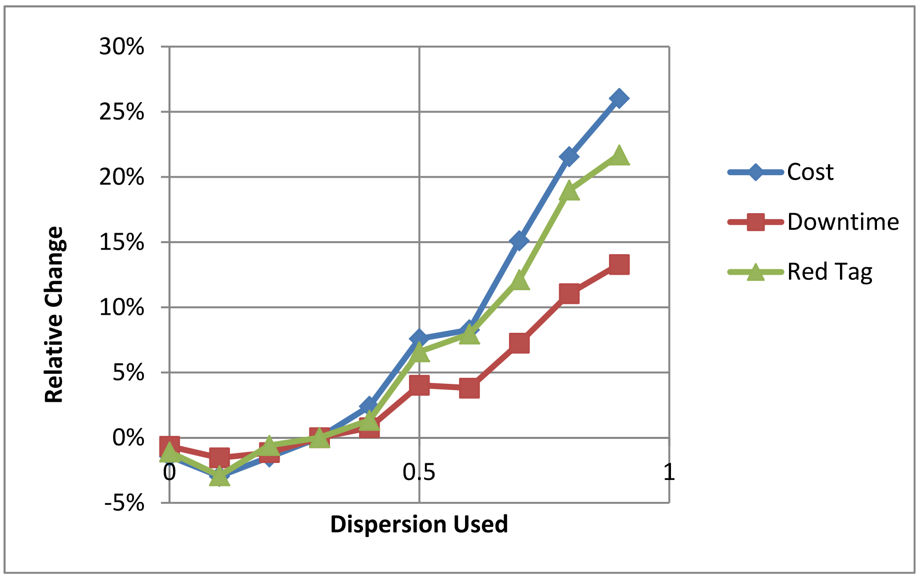


Figure 1-13 Sensitivity to the Dispersion in Residual Drift Capacity, Relative Changes from Baseline

Sensitivity to Using an Alternate Calculation Method for Residual Drift

To further assess the sensitivities to the effects of residual drifts, Table 1-31 compares the results when the residual drifts are predicted from the simplified approach in Section 5.4 of ATC-58 Volume I (baseline) versus predicting the residual drifts directly from the dynamic analyses of the nonlinear structural model. It is noted that in the latter case of using the nonlinear structural model directly, the structural model utilized in this example is known to have an unloading stiffness that is too stiff, which is known to result in an overprediction of the residual drifts

Table 1-31 shows that this difference in residual drift prediction method leads to meaningful increases in the annualize cost and probability of red tagging and slight increases in the other performance metrics.

Table 1-31 Sensitivity to Using an Alternative Calculation Method for Residual Drift, Relative Changes from Baseline

Calculation Method	Cost	Downtime	Fatalities	Injuries	Collapse	Red Tag
ATC-58 Equation (BL)	$80,114	2.6	0.0841	0.0102	0.0011052	0.004083
Maximum Residual from Model	$102,724	2.9	0.0916	0.011	0.0011381	0.005127
Relative Change	28%	13%	9%	8%	3%	26%

Sensitivity to Which Fragilities are Included in the Loss Assessment

Table 1-32 disaggregates the overall Expected Annual Loss (EAL) and Red Tag Probability (RTP) values to show what specific aspects of the performance assessment contribute to the final overall predicted values (e.g. the overall $80,114 prediction for EAL). These tables were created by systematically adding or removing items in the PACT model.

Table 1-32a shows that over half ($49,000) of the total $80,000 EAL comes from either collapse or residual drift and just under half ($37,000) comes from other damage to the damageable components (performance groups) in the building. Of collapse and residual drift contribution to EAL, about 2/5 comes from the effects of collapse and 3/5 comes from the effects of residual drift. Of the other performance groups in the building, most of the EAL comes from the damageability to the partition walls.

Table 1-32 Summary of Specific Contributions to Losses and Red Tagging Probabilities: (a) Collapse and Residual Drift, (b) Other Specific Fragilities

(a)

Performance Group	Expected Annual Loss (EAL)	EAL [% of Building Cost]	Annual Probability of Red Tag (RTP)
Collapse	$22,962	0.11%	0.001081
Residual Drift	$31,972	0.15%	0.001334
∑ =	$54,934	0.26%	0.002415
Collapse & Residual Drift Together	$48,886	0.23%	0.002127
Difference (Double Counting)	12%	--	14%

(b)

Performance Group	Expected Annual Loss (EAL)	EAL [% of Building Cost]	Contribution to EAL	Annual Probability of Red Tag	Contribution to RTP
Partitions	$24,701	0.12%	66%	0.0	0%
Beam/Column joints only	$2,470	0.01%	7%	0.00118	30%
Slab/Gravity Columns only	$2,857	0.01%	8%	0.00113	29%
Glazing Only	$5,167	0.02%	14%	0.0	0%
All Others Combined	$1,998	0.01%	5%	0.00165	42%
∑ All Components:	$37,194	0.18%	100%	0.00340	100%

Sensitivity to Partition Fragility Quantity Determination

The costing of the partition fragility used in the PACT projects (C1011.001a) was based on 13' x 100' panels. The Benchmark project to which the PACT projects will later be compared had partition costs based on 8' x 8' panels. Since there was a significant difference in height between the two partition unit quantities, a decision had to be made of whether to match the total *horizontal length* of partitions or the total *area* of partitions. This is a seemingly simple decision, but Table 1-33 shows that this has measurable effects on the resulting predictions of annual cost and downtime (a 17% and 27% change). When the partition quantities are based on equal length, the result is an equivalent number of 100' x 13' partitions of 10.72 units for the first story and 14.48 units for the stories above; this is comparable 6.6 and 8.9 units, respectively, for the baseline model what was based on equal partition areas.

Table 1-33 Significance of Basing Partition Quantities on Area versus Length

Partition Quantity Basis	Cost	Downtime	Fatalities	Injuries	Collapse	Red Tag
Area (BL)	$80,114	2.58	0.0841	0.0102	0.0011	0.0041
Horizontal Length	$93,468	3.28	0.0855	0.0102	0.0011	0.0041
Relative Change	17%	27%	2%	0%	-2%	0%

1.1.7 Brief Comparison of ATC-58 Loss Predictions to Predictions from the Previous PEER Benchmarking Research Study

In order to provide a rough sanity check of the Expected Annual Loss (EAL) predictions from PACT, this section compares the PACT predictions to the EAL predictions from a similar building assessed in the recent PEER Benchmark study (Goulet et al. 2007, Haselton et al. 2008). Note that the building models differ slightly between this PACT example and the previous Benchmark study, so the predictions are expected to be similar but not exactly the same (e.g. the T_1 of the model for this PACT study is 1.13s and was 1.02s in the model used in the Benchmark study). For this comparison to the Benchmark study, a PACT project was created that only included the performance groups that were used in the Benchmark study. The total replacement cost of the building was also made equal to the total replacement cost that was used for the Benchmark study, $8,900,000. The core and shell replacement cost was made equal to roughly 50% of the total replacement cost, $4,500,000. For the final comparisons, all of the parameters were made to be as similar as possible to the Benchmark study. Additionally this section reiterates the effects of some aspects of the assessment, such as variations to the partition quantities and the seismic hazard curve, in order to more clearly show the reasons for the differences between the Benchmark results and the baseline PACT results shown elsewhere in this Section 1.1 RC SMF example.

Table 1-34 displays the process of comparing the PACT baseline model results to the results of the original Benchmark Study (Goulet et al. 2007, Haselton et al. 2008). The comparison between the PACT EAL predictions and the Benchmark predictions are detailed as follows:

- The overall comparison of the final PACT EAL prediction ($80,114 from row six) to the Benchmark prediction ($66,460 from row one) shows that the two predictions are relatively similar, but these two values are not actually directly comparable because the items included in each assessment are not the same.
- The second row in Table 1-34 shows the PACT prediction that is intentionally made to be comparable to the Benchmark prediction. For this comparison, the PACT model contains only the fragilities used in the Benchmark model, contains no fragility for residual drift, uses the Benchmark hazard curve, and has the replacement cost set to be $8.9 million (as in the Benchmark study). This direct comparison shows that the PACT prediction is larger than the Benchmark study prediction by 33%; these two predictions are actually reasonably similar for loss predictions using two different methodologies.
- Rows three through five of Table 1-34 then show the effects of the differences between the full PACT model (row six) and the reduced PACT model used for the Benchmark comparison (row two). These comparisons show that using the USGS hazard curve instead of the Benchmark curve reduces the EAL by more than a factor of two, increasing the building replacement cost increases the EAL by 35%, and the effects of residual drift increases the EAL by 44%.

Table 1-34 Comparisons between PACT Predictions and Benchmark Study Prediction

Index	Analysis	Basis of Fragility Quantities	Additional Fragilities Added	Residual Drift Included	Hazard Curve Used	Replace. Cost Used ($Million)	Expected Annual Loss (EAL)	EA Down.	EA Red Tag Prob.	EA Fatal.
1	**Benchmark**	**Benchmark**	**No**	**No**	**Benchmark**	**8.9**	**$66,460**	--	--	--
2	PACT	Benchmark	No	No	Benchmark	8.9	$88,703	4.7	0.0063	0.1583
3	PACT	Benchmark	No	No	USGS	8.9	$39,585	2.1	0.0035	0.0821
4	PACT	Benchmark	No	No	USGS	21.6	$53,414	2.1	0.0034	0.0824
5	PACT	Benchmark	No	Yes	USGS	21.0	$76,993	2.4	0.0038	0.0842
6	**PACT (BL)**	**Combination**	**Yes**	**Yes**	**USGS**	**21.0**	**$80,113**	**2.6**	**0.0041**	**0.0841**

1.1.8 Appendix: More Detailed Comparisons Between Non-Linear and Simplified Analysis Method Results

This section provides more detailed comparisons between the predictions using the nonlinear analysis and the simplified linear analysis methods. Table 1-35 through Table 1-42 document the structural response predictions (both median and dispersion) between the two analysis methods and Figure 1-14 through Figure 1-40 show these same structural response predictions in graphical format. One notable observation from the figures is that the direction three responses (the non-directional responses used in PACT) show no dispersion; this was an error in the previous PACT implementation and this has been corrected for the updated versions of PACT.

Table 1-43 through Table 1-46 and Figure 1-41 through Figure 1-44 more fully document the resulting PACT predictions for both the nonlinear analysis and simplified linear analysis methods. These tables and figures extend the comparisons of Section 1.1.5 to include the results for each of the eight intensity levels and for the 10th and 90th percentiles of the predicted performance metrics.

Table 1-35 Demand Vectors, Intensity 1, Conditioned on No Collapse

Intensity 1: $Sa(T_1)$=0.16g				
	Non-Linear		Simplified	
Parameter	Median	Logarithmic Standard Deviation	Median	Dispersion Used
IDR_max_4	0.002	0.14	0.003	0.43
IDR_max_3	0.004	0.18	0.004	0.43
IDR_max_2	0.005	0.21	0.004	0.43
IDR_max_1	0.005	0.19	0.005	0.43
PFA_5 (g)	0.233	0.11	0.123	0.43
PFA_4 (g)	0.188	0.17	0.120	0.43
PFA_3 (g)	0.181	0.15	0.121	0.43
PFA_2 (g)	0.155	0.21	0.122	0.43
PGA (g)	0.092	0.24	0.092	0.43

Table 1-36 Demand Vectors, Intensity 2, Conditioned on No Collapse

Intensity 2: $Sa(T_1)$=0.39g				
	Non-Linear		Simplified	
Parameter	Median	Logarithmic Standard Deviation	Median	Dispersion Used
IDR_max_4	0.004	0.15	0.008	0.43
IDR_max_3	0.008	0.27	0.010	0.43
IDR_max_2	0.011	0.25	0.011	0.43
IDR_max_1	0.011	0.28	0.013	0.43
PFA_5 (g)	0.337	0.13	0.251	0.43
PFA_4 (g)	0.294	0.12	0.244	0.43
PFA_3 (g)	0.292	0.14	0.247	0.43
PFA_2 (g)	0.298	0.20	0.249	0.43
PGA (g)	0.213	0.19	0.213	0.43

Table 1-37 Demand Vectors, Intensity 3, Conditioned on No Collapse

Intensity 3: $Sa(T_1)$=0.62g				
	Non-Linear		Simplified	
Parameter	Median	Logarithmic Standard Deviation	Median	Dispersion Used
IDR_max_4	0.006	0.34	0.013	0.53
IDR_max_3	0.014	0.24	0.015	0.53
IDR_max_2	0.018	0.26	0.017	0.53
IDR_max_1	0.016	0.33	0.020	0.53
PFA_5 (g)	0.430	0.11	0.358	0.53
PFA_4 (g)	0.356	0.14	0.347	0.53
PFA_3 (g)	0.383	0.12	0.350	0.53
PFA_2 (g)	0.425	0.12	0.354	0.53
PGA (g)	0.343	0.20	0.343	0.53

Table 1-38 Demand Vectors, Intensity 4, Conditioned on No Collapse

Intensity 4: $Sa(T_1)$=0.84g				
	Non-Linear		Simplified	
Parameter	Median	Logarithmic Standard Deviation	Median	Dispersion Used
IDR_max_4	0.008	0.43	0.017	0.67
IDR_max_3	0.020	0.30	0.021	0.67
IDR_max_2	0.027	0.37	0.022	0.67
IDR_max_1	0.027	0.43	0.027	0.67
PFA_5 (g)	0.482	0.13	0.434	0.67
PFA_4 (g)	0.411	0.14	0.422	0.67
PFA_3 (g)	0.465	0.14	0.426	0.67
PFA_2 (g)	0.525	0.18	0.430	0.67
PGA (g)	0.472	0.18	0.472	0.67

Table 1-39 Demand Vectors, Intensity 5, Conditioned on No Collapse

Intensity 5: $Sa(T_1)$=1.07g				
	Non-Linear		Simplified	
Parameter	Median	Logarithmic Standard Deviation	Median	Dispersion Used
IDR_max_4	0.010	0.49	0.022	0.67
IDR_max_3	0.023	0.34	0.026	0.67
IDR_max_2	0.032	0.32	0.028	0.67
IDR_max_1	0.031	0.34	0.034	0.67
PFA_5 (g)	0.506	0.14	0.429	0.67
PFA_4 (g)	0.432	0.16	0.417	0.67
PFA_3 (g)	0.470	0.18	0.421	0.67
PFA_2 (g)	0.589	0.23	0.425	0.67
PGA (g)	0.528	0.26	0.528	0.67

Table 1-40 Demand Vectors, Intensity 6, Conditioned on No Collapse

Intensity 6: $Sa(T_1)$=1.30g				
	Non-Linear		Simplified	
Parameter	Median	Logarithmic Standard Deviation	Median	Dispersion Used
IDR_max_4	0.011	0.68	0.026	0.67
IDR_max_3	0.024	0.37	0.031	0.67
IDR_max_2	0.039	0.35	0.033	0.67
IDR_max_1	0.038	0.40	0.040	0.67
PFA_5 (g)	0.552	0.18	0.476	0.67
PFA_4 (g)	0.471	0.17	0.462	0.67
PFA_3 (g)	0.532	0.17	0.467	0.67
PFA_2 (g)	0.698	0.22	0.471	0.67
PGA (g)	0.664	0.23	0.664	0.67

Table 1-41 Demand Vectors, Intensity 7, Conditioned on No Collapse

Intensity 7: $Sa(T_1)$=1.53g				
	Non-Linear		Simplified	
Parameter	Median	Logarithmic Standard Deviation	Median	Dispersion Used
IDR_max_4	0.018	0.77	0.030	0.67
IDR_max_3	0.029	0.46	0.036	0.67
IDR_max_2	0.043	0.35	0.039	0.67
IDR_max_1	0.040	0.42	0.046	0.67
PFA_5 (g)	0.654	0.22	0.525	0.67
PFA_4 (g)	0.591	0.19	0.509	0.67
PFA_3 (g)	0.597	0.15	0.514	0.67
PFA_2 (g)	0.848	0.25	0.519	0.67
PGA (g)	0.829	0.24	0.829	0.67

Table 1-42 Demand Vectors, Intensity 8, Conditioned on No Collapse

Intensity 8: $Sa(T_1)$=1.76g				
	Non-Linear		Simplified	
Parameter	Median	Logarithmic Standard Deviation	Median	Dispersion Used
IDR_max_4	0.017	0.38	0.034	0.67
IDR_max_3	0.032	0.26	0.041	0.67
IDR_max_2	0.049	0.43	0.044	0.67
IDR_max_1	0.047	0.45	0.053	0.67
PFA_5 (g)	0.633	0.15	0.574	0.67
PFA_4 (g)	0.538	0.31	0.557	0.67
PFA_3 (g)	0.635	0.10	0.563	0.67
PFA_2 (g)	0.909	0.31	0.568	0.67
PGA (g)	1.027	0.08	1.027	0.67

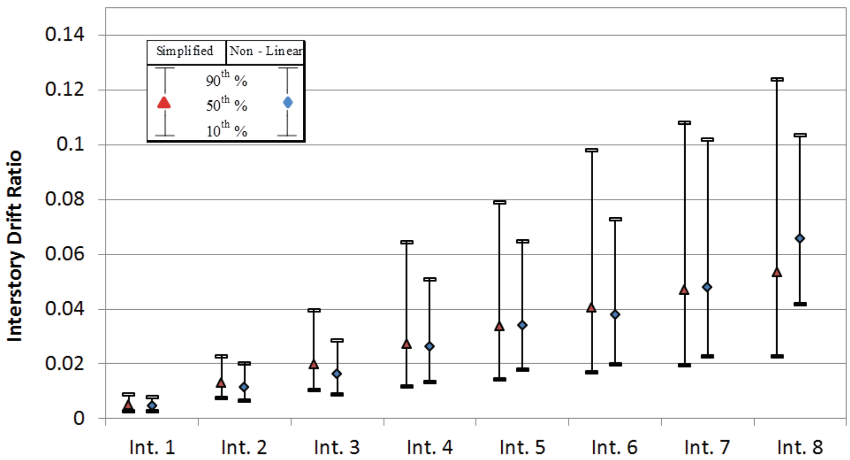


Figure 1-14 10% - 50% - 90% Demand Vectors, Interstory Drift Ratio, Direction 1, Story 1, Conditioned on No Collapse

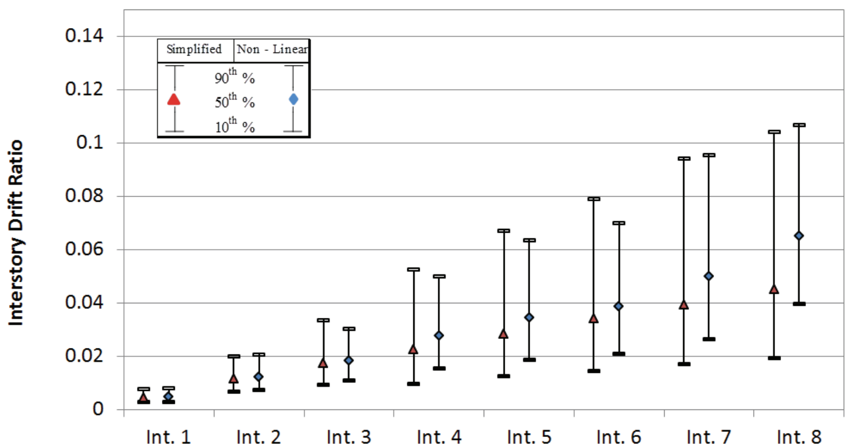


Figure 1-15 10% - 50% - 90% Demand Vectors, Interstory Drift Ratio, Direction 1, Story 2, Conditioned on No Collapse

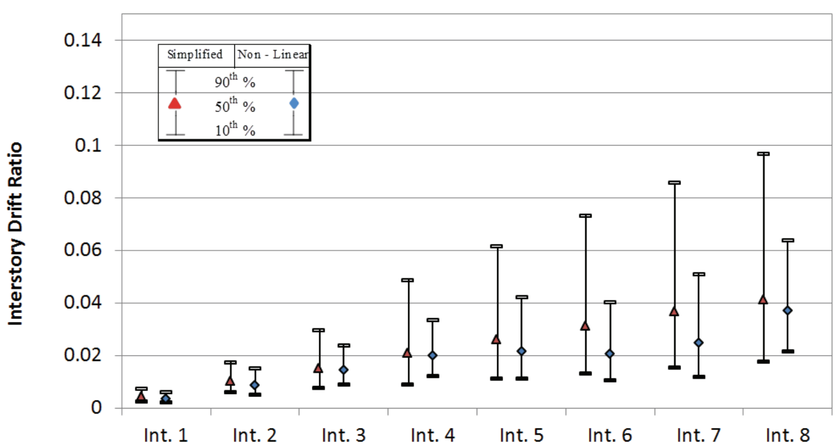


Figure 1-16 10% - 50% - 90% Demand Vectors, Interstory Drift Ratio, Direction 1, Story 3, Conditioned on No Collapse

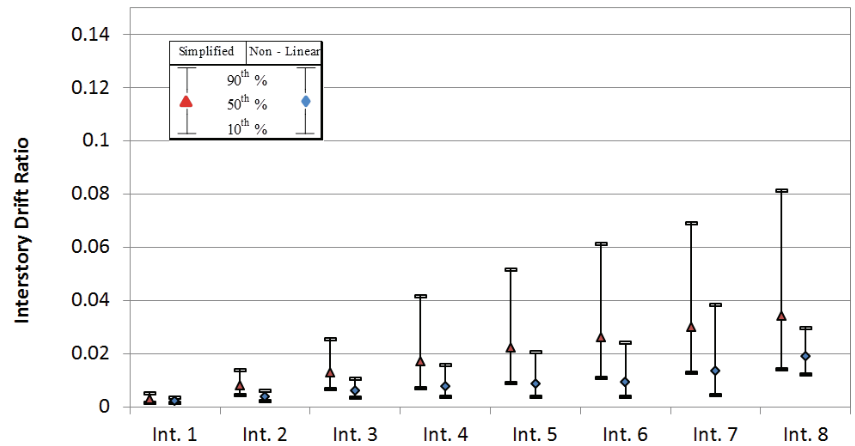


Figure 1-17 10% - 50% - 90% Demand Vectors, Interstory Drift Ratio, Direction 1, Story 4, Conditioned on No Collapse

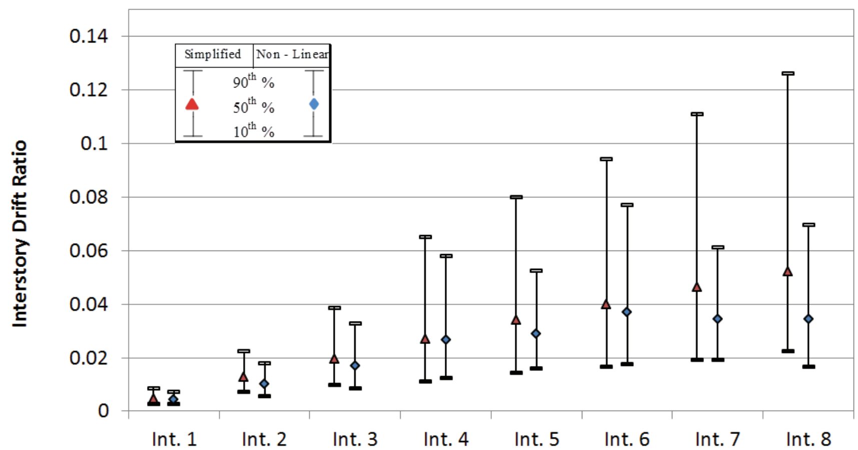


Figure 1-18 10% - 50% - 90% Demand Vectors, Interstory Drift Ratio, Direction 2, Story 1, Conditioned on No Collapse

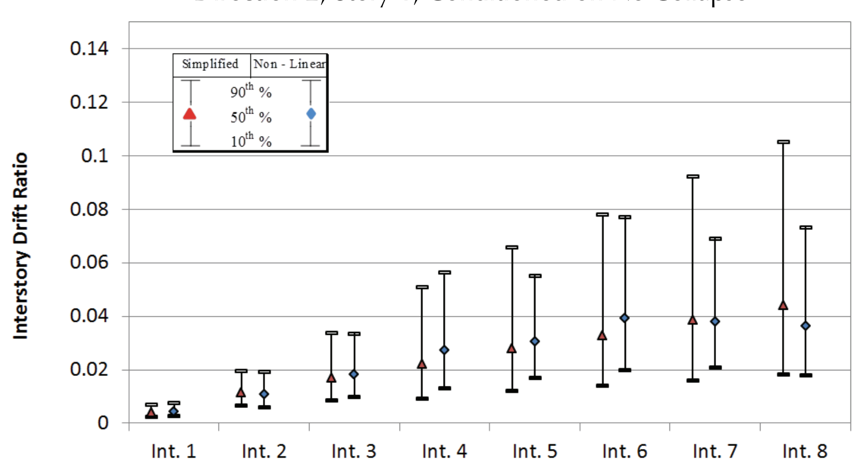


Figure 1-19 10% - 50% - 90% Demand Vectors, Interstory Drift Ratio, Direction 2, Story 2, Conditioned on No Collapse

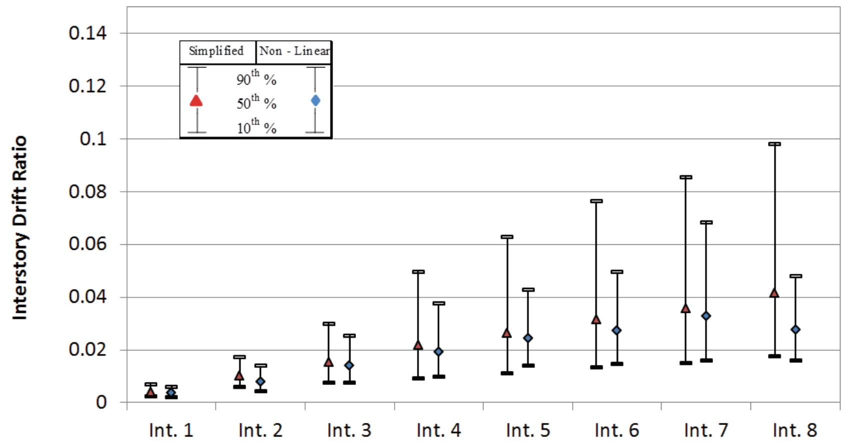


Figure 1-20 10% - 50% - 90% Demand Vectors, Interstory Drift Ratio, Direction 2, Story 3, Conditioned on No Collapse

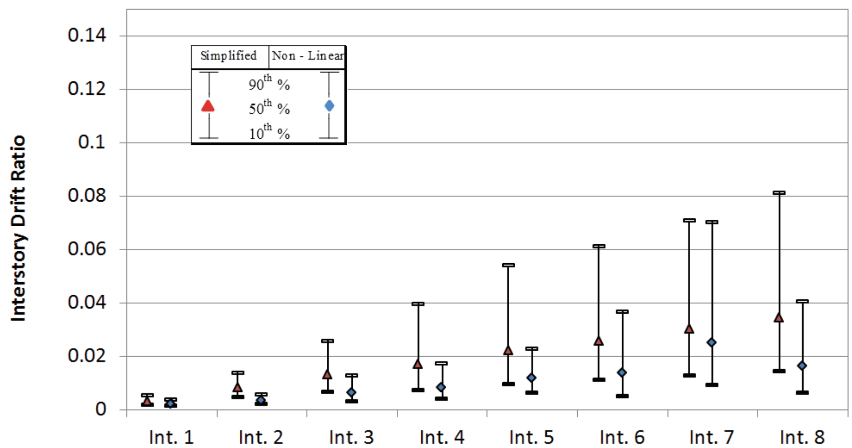


Figure 1-21 10% - 50% - 90% Demand Vectors, Interstory Drift Ratio, Direction 2, Story 4, Conditioned on No Collapse

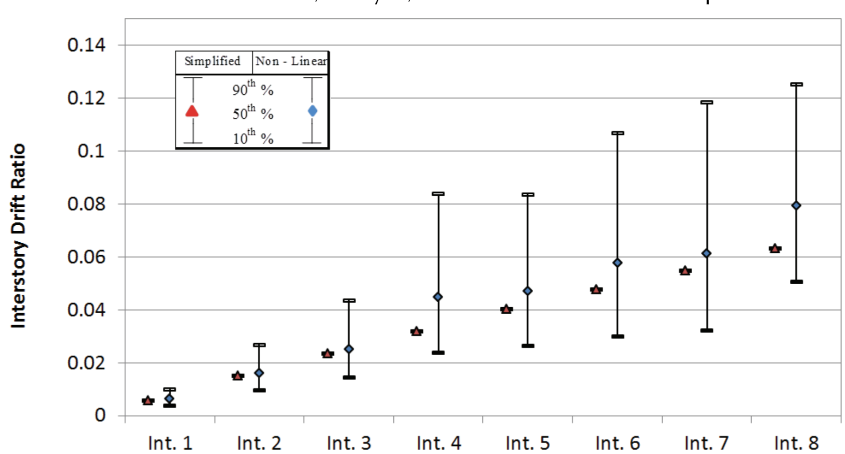


Figure 1-22 10% - 50% - 90% Demand Vectors, Interstory Drift Ratio, Direction 3, Story 1, Conditioned on No Collapse

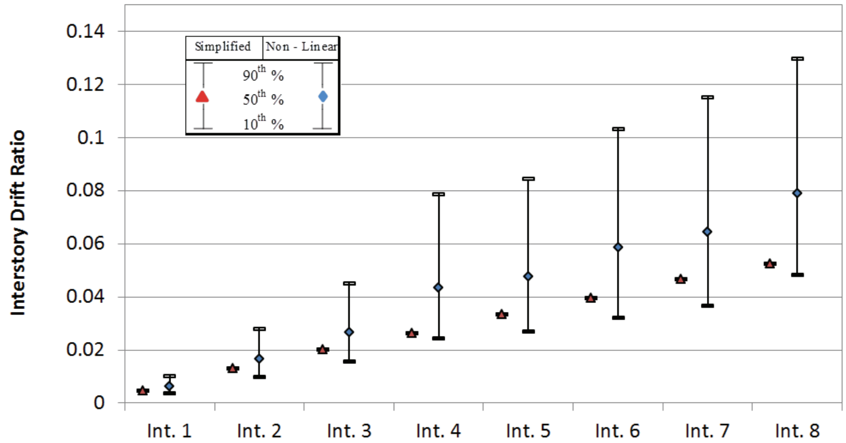


Figure 1-23 10% - 50% - 90% Demand Vectors, Interstory Drift Ratio, Direction 3, Story 2, Conditioned on No Collapse

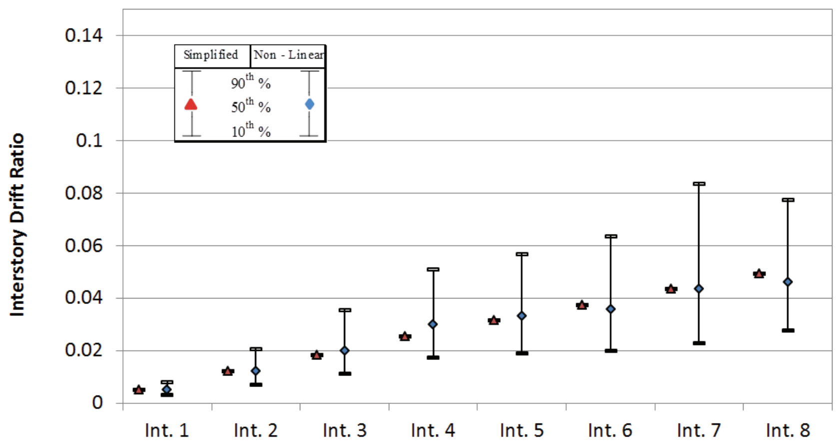


Figure 1-24 10% - 50% - 90% Demand Vectors, Interstory Drift Ratio, Direction 3, Story 3, Conditioned on No Collapse

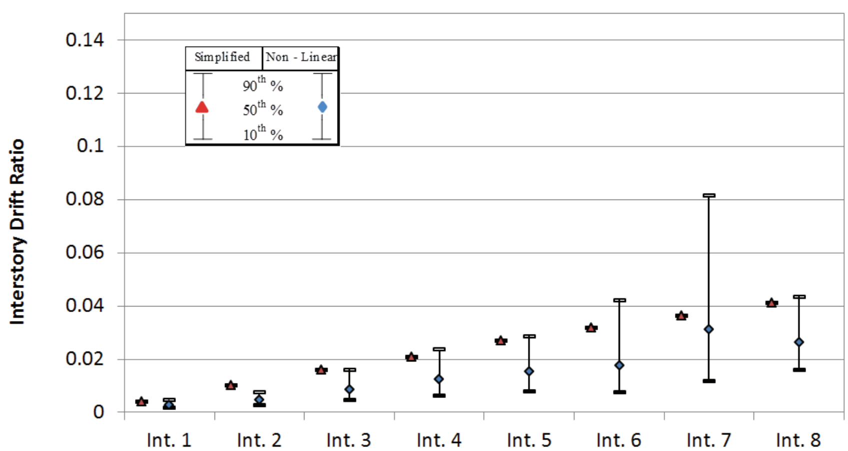


Figure 1-25 10% - 50% - 90% Demand Vectors, Interstory Drift Ratio, Direction 3, Story 4, Conditioned on No Collapse

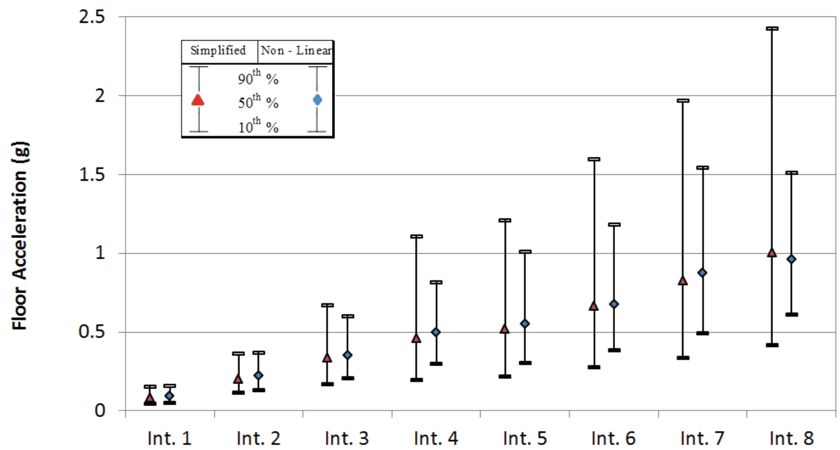


Figure 1-26 10% - 50% - 90% Demand Vectors, Floor Acceleration, Direction 1, Floor 1, Conditioned on No Collapse

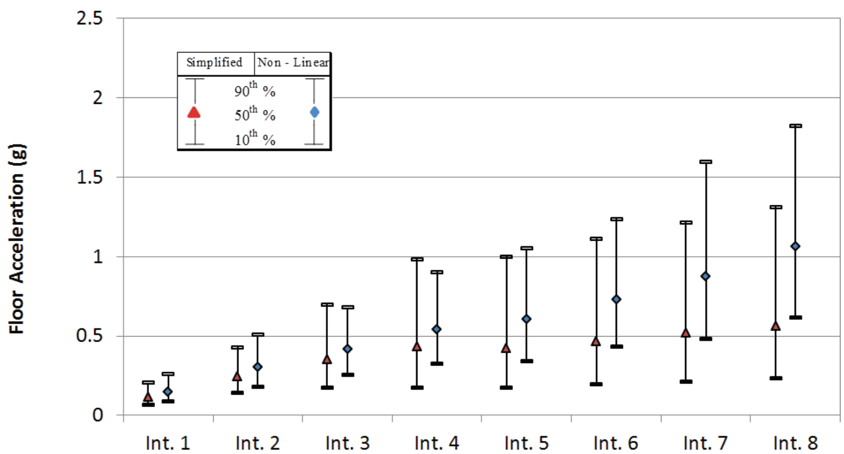


Figure 1-27 10% - 50% - 90% Demand Vectors, Floor Acceleration, Direction 1, Floor 2, Conditioned on No Collapse

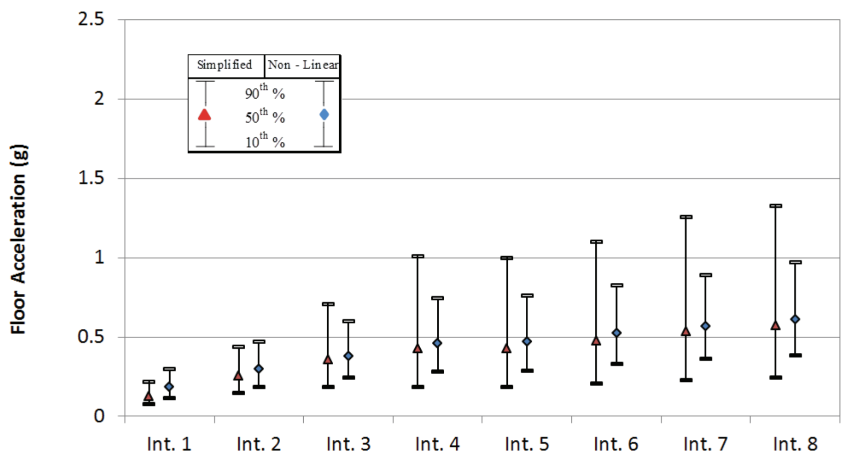


Figure 1-28 10% - 50% - 90% Demand Vectors, Floor Acceleration, Direction 1, Floor 3, Conditioned on No Collapse

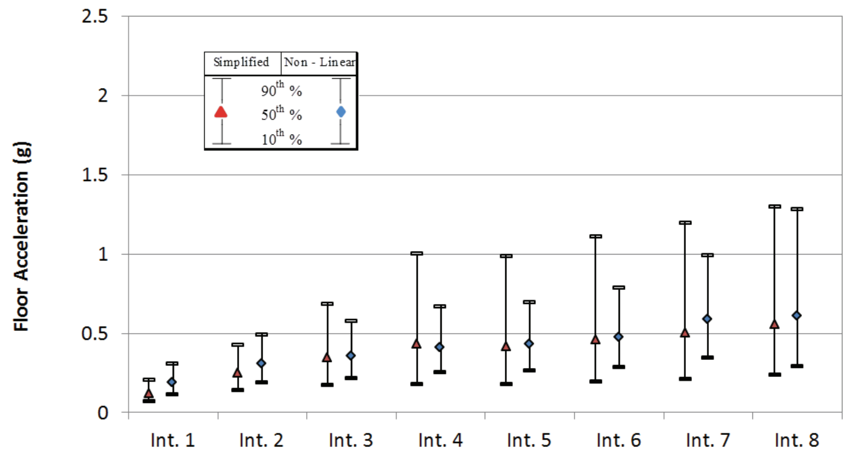


Figure 1-29 10% - 50% - 90% Demand Vectors, Floor Acceleration, Direction 1, Floor 4, Conditioned on No Collapse

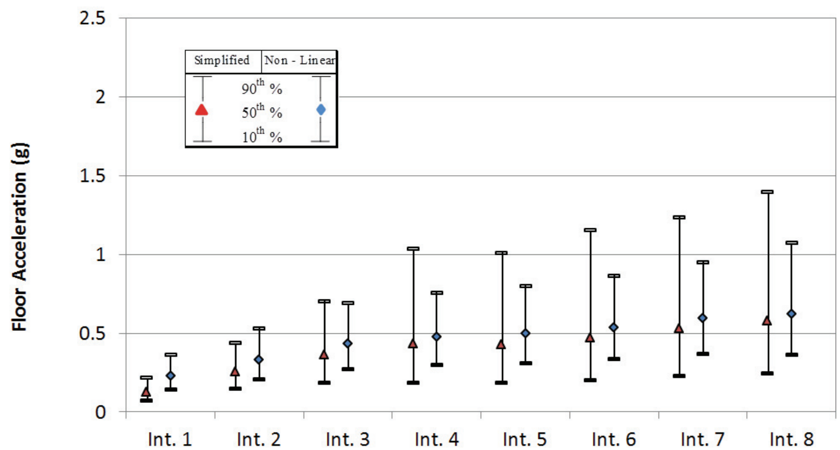


Figure 1-30 10% - 50% - 90% Demand Vectors, Floor Acceleration, Direction 1, Floor 5, Conditioned on No Collapse

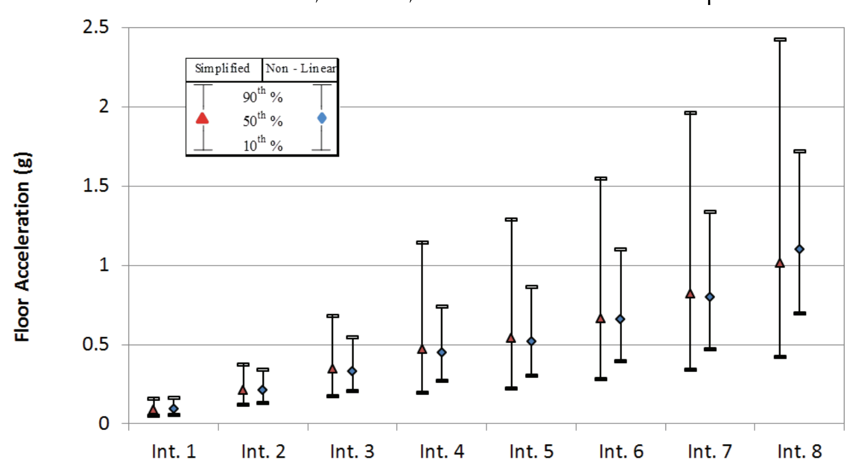


Figure 1-31 10% - 50% - 90% Demand Vectors, Floor Acceleration, Direction 2, Floor 1, Conditioned on No Collapse

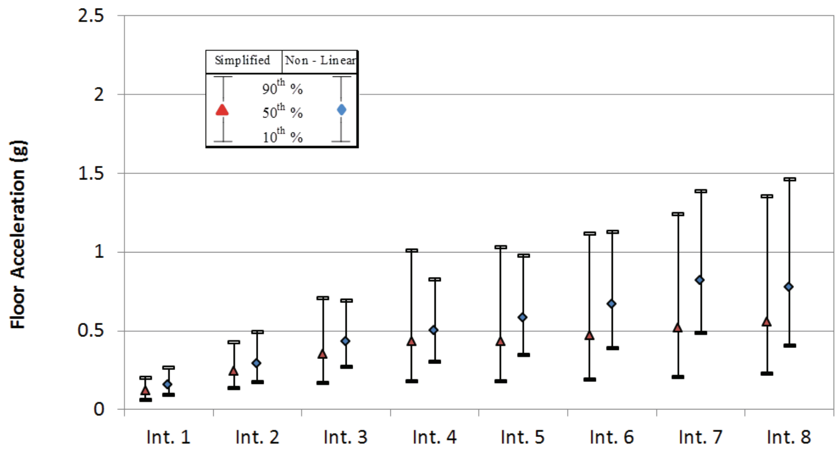


Figure 1-32 10% - 50% - 90% Demand Vectors, Floor Acceleration, Direction 2, Floor 2, Conditioned on No Collapse

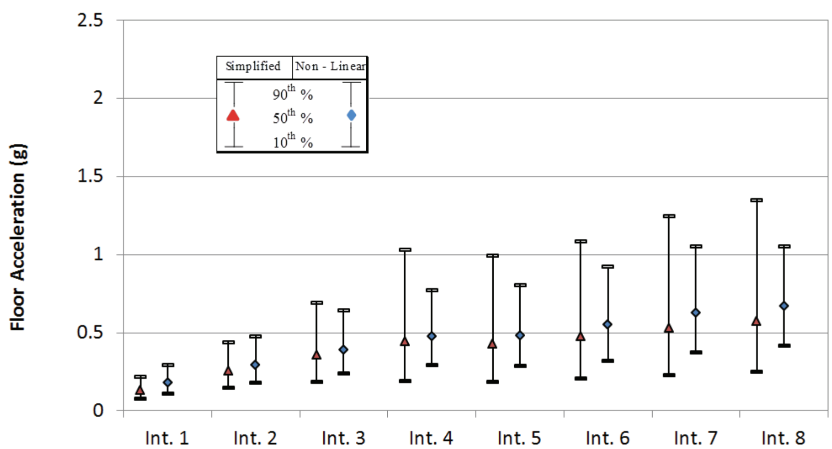


Figure 1-33 10% - 50% - 90% Demand Vectors, Floor Acceleration, Direction 2, Floor 3, Conditioned on No Collapse

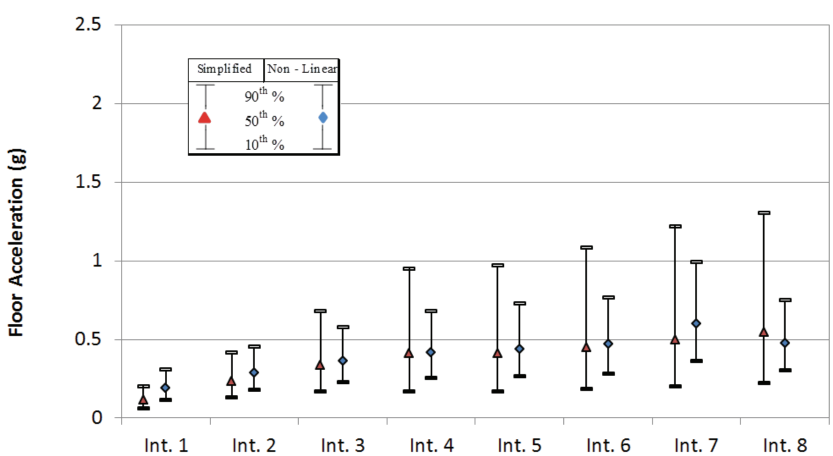


Figure 1-34 10% - 50% - 90% Demand Vectors, Floor Acceleration, Direction 2, Floor 4, Conditioned on No Collapse

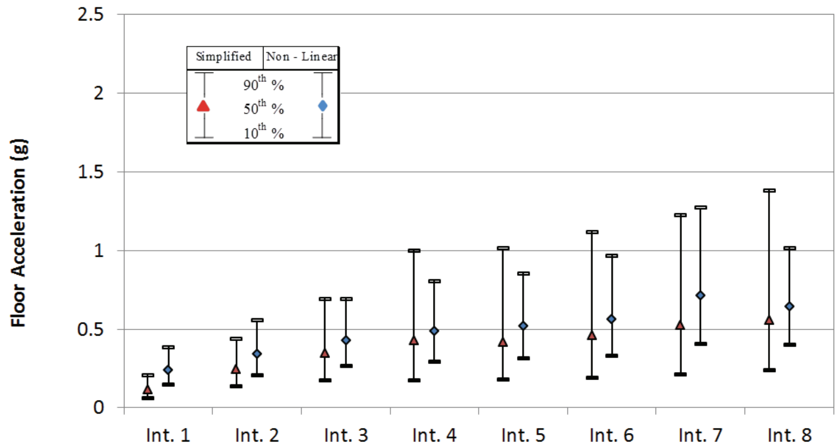


Figure 1-35 10% - 50% - 90% Demand Vectors, Floor Acceleration, Direction 2, Floor 5, Conditioned on No Collapse

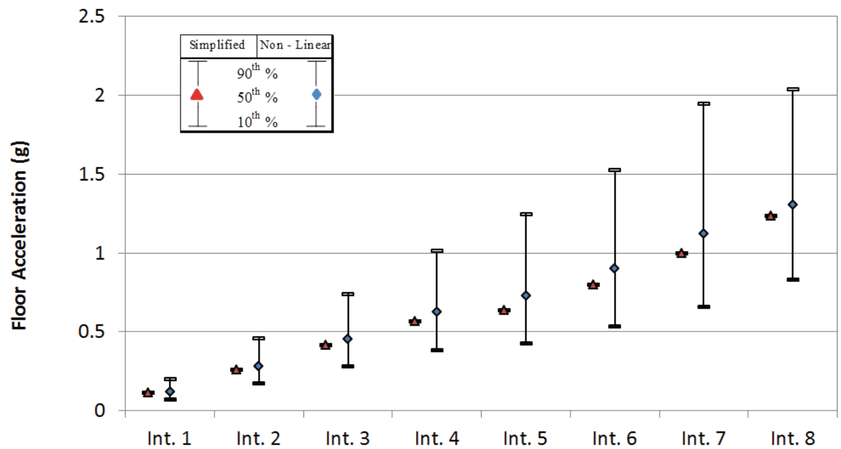


Figure 1-36 10% - 50% - 90% Demand Vectors, Floor Acceleration, Direction 3, Floor 1, Conditioned on No Collapse

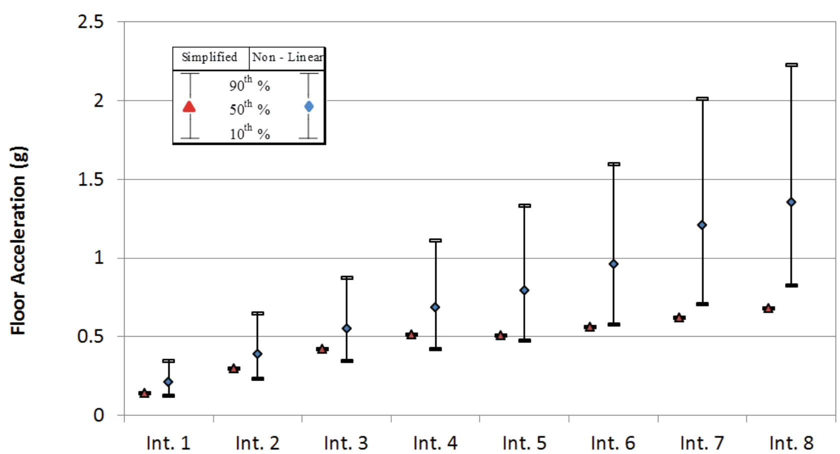


Figure 1-37 10% - 50% - 90% Demand Vectors, Floor Acceleration, Direction 3, Floor 2, Conditioned on No Collapse

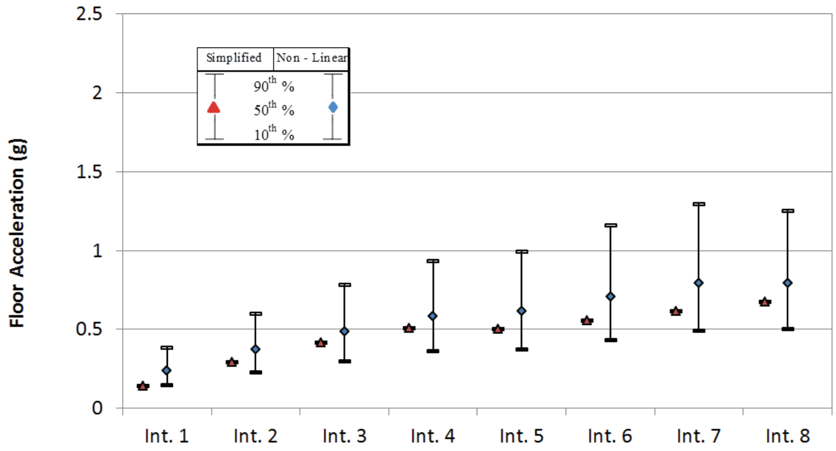


Figure 1-38 10% - 50% - 90% Demand Vectors, Floor Acceleration, Direction 3, Floor 3, Conditioned on No Collapse

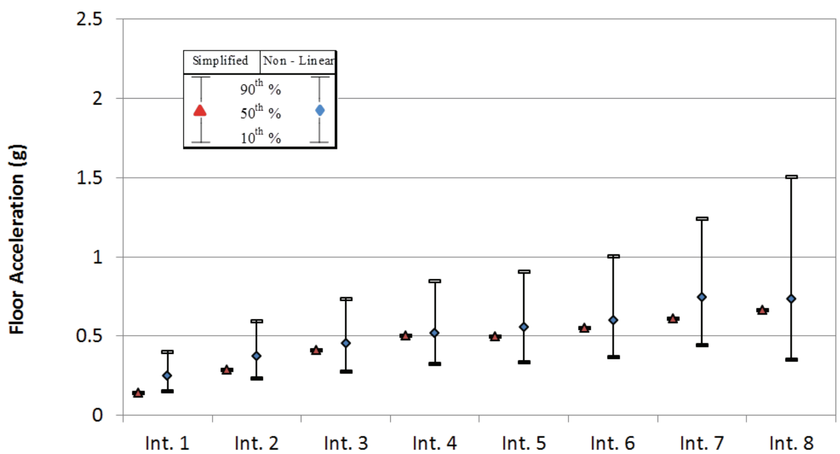


Figure 1-39 10% - 50% - 90% Demand Vectors, Floor Acceleration, Direction 3, Floor 4, Conditioned on No Collapse

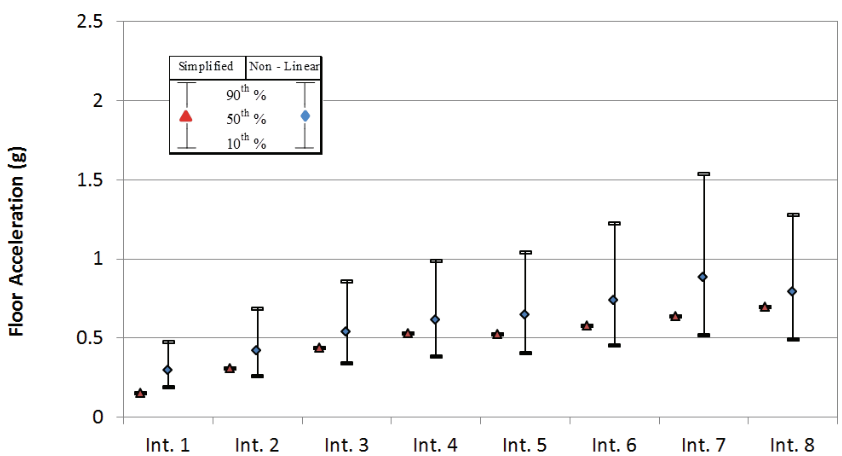


Figure 1-40 10% - 50% - 90% Demand Vectors, Floor Acceleration, Direction 3, Floor 5, Conditioned on No Collapse

Table 1-43 Percentiles of Losses (10%/50%/90%) for Each Intensity Level – Comparison of the Non-Linear and Simplified Linear Analysis Methods

Loss	10th Percentile			50th Percentile			90th Percentile		
Intensity	Non – Linear (BL)	Simp. Linear	Relative Change	Non – Linear (BL)	Simp. Linear	Relative Change	Non – Linear (BL)	Simp. Linear	Relative Change
1	$230,230	$302,344	31%	$433,091	$479,891	11%	$768,824	$730,149	-5%
2	$801,065	$1,266,941	58%	$1,470,155	$1,870,831	27%	$2,576,375	$292,1601	13%
3	$1,803,849	$2,413,927	34%	$3,078,164	$3,430,300	11%	$2,096,2151	$20,964,599	0%
4	$3,621,767	$3,308,560	-9%	$20,935,379	$5,082,052	-76%	$20,987,076	$20,978,502	0%
5	$4,159,697	$4,410,366	6%	$20,937,030	$20,934,787	0%	$20,987,406	$20,986,957	0%
6	$5,362,910	$5,628,889	5%	$20,942,930	$20,943,310	0%	$20,988,586	$20,988,662	0%
7	$20,905,858	$20,904,658	0%	$20,947,699	$20,947,032	0%	$20,989,540	$20,989,406	0%
8	$20,909,985	$20,906,974	0%	$20,949,992	$20,948,319	0%	$20,989,998	$20,989,664	0%

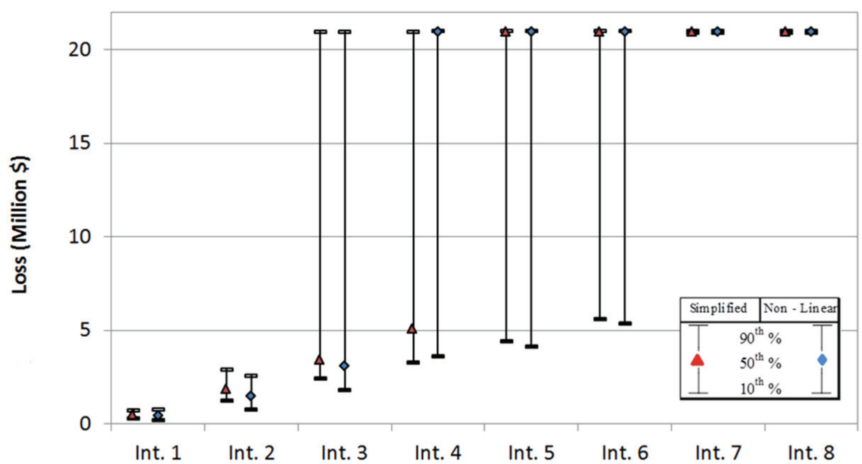


Figure 1-41 Percentiles of Loss (10%/50%/90%) for Each Intensity Level – Comparison of the Non-Linear and Simplified Linear Analysis Methods

Table 1-44 Percentiles of Repair Time (10%/50%/90%) for Each Intensity Level – Comparison of the Non-Linear and Simplified Linear Analysis Methods

Repair Time (days)	10th Percentile			50th Percentile			90th Percentile		
Intensity	Non – Linear (BL)	Simp. Linear	Relative Change	Non – Linear (BL)	Simp. Linear	Relative Change	Non – Linear (BL)	Simp. Linear	Relative Change
1	10.6	13.0	23%	23.2	26.2	13%	46.4	46.7	1%
2	41.3	62.0	50%	79.4	96.8	22%	141.4	166.3	18%
3	86.9	112.9	30%	148.4	160.8	8%	396.2	396.5	0%
4	168.5	147.6	-12%	394.4	220.2	-44%	398.7	397.9	0%
5	182.7	184.9	1%	393.6	393.5	0%	398.7	398.7	0%
6	238.5	222	-7%	394.3	394.3	0%	398.9	398.9	0%
7	390.6	390.5	0%	394.8	394.7	0%	399.0	398.9	0%
8	391.0	390.7	0%	395.0	394.8	0%	399.0	399.0	0%

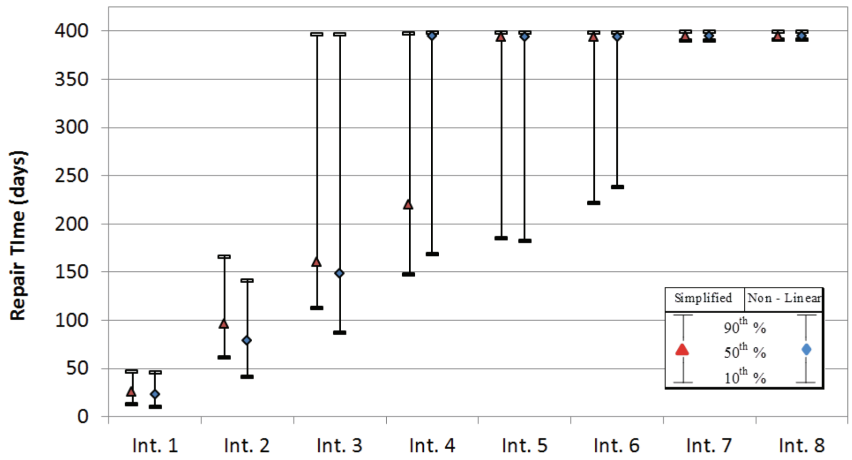


Figure 1-42 Percentiles of Repair Time (10%/50%/90%) for Each Intensity Level – Comparison of the Non-Linear and Simplified Linear Analysis Methods

Table 1-45 Percentiles of Injuries (10%/50%/90%) for Each Intensity Level – Comparison of the Non-Linear and Simplified Linear Analysis Methods

Injuries	10th Percentile			50th Percentile			90th Percentile		
Intensity	Non – Linear (BL)	Simp. Linear	Relative Change	Non – Linear (BL)	Simp. Linear	Relative Change	Non – Linear (BL)	Simp. Linear	Relative Change
1	0	0	0%	0	0	0%	0.0	0.0	0%
2	0	0	0%	0	0	0%	0.4	0.0	-92%
3	0	0	0%	0	0	0%	0.9	0.8	-12%
4	0	0	0%	0	0	0%	5.2	2.3	-56%
5	0	0	0%	0	0	0%	14.7	14.4	-3%
6	0	0	0%	0	0	0%	19.3	32.1	67%
7	0	0	0%	0	0	0%	23.0	21.1	-8%
8	0	0	0%	0	0	0%	23.7	23.2	-2%

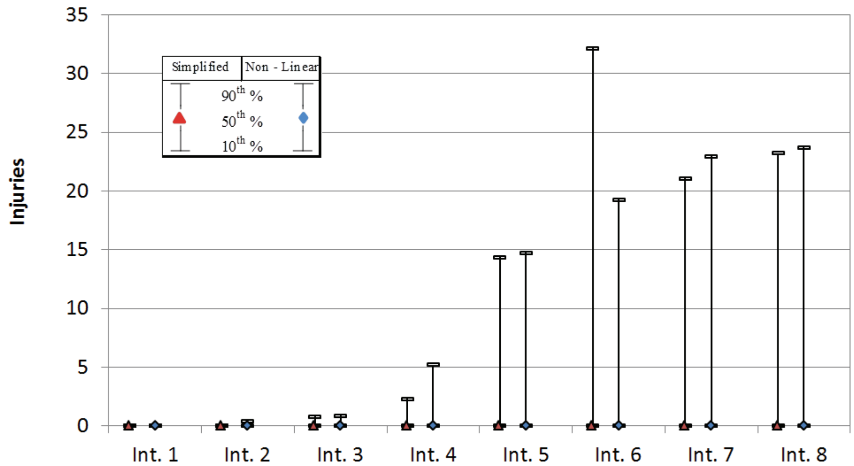


Figure 1-43 Percentiles of Injuries (10%/50%/90%) for Each Intensity Level – Comparison of the Non-Linear and Simplified Linear Analysis Methods

Table 1-46 Percentiles of Casualties (10%/50%/90%) for Each Intensity Level – Comparison of the Non-Linear and Simplified Linear Analysis Methods

Casualties	10th Percentile			50th Percentile			90th Percentile		
Intensity	Non – Linear (BL)	Simp. Linear	Relative Change	Non – Linear (BL)	Simp. Linear	Relative Change	Non – Linear (BL)	Simp. Linear	Relative Change
1	0	0	0%	0	0	0%	0.0	0.0	0%
2	0	0	0%	0	0	0%	1.7	0.3	-83%
3	0	0	0%	0	0	0%	7.8	7.8	-1%
4	0	0	0%	0	0	0%	16.7	17.8	7%
5	0	0	0%	0	0	0%	122.5	129.8	6%
6	0	0	0%	0	0	0%	168.8	163.7	-3%
7	0	0	0%	0	0	0%	201.5	190.4	-6%
8	0	0	0%	0	0	0%	210.3	208.4	-1%

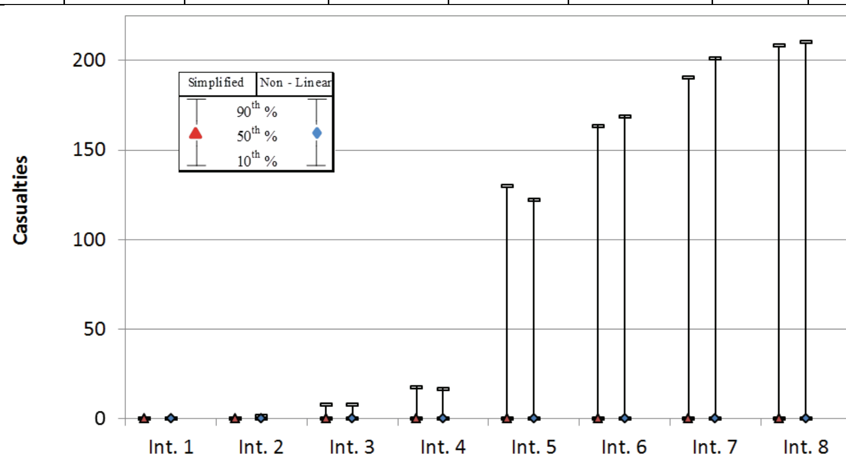


Figure 1-44 Percentiles of Casualties (10%/50%/90%) for Each Intensity Level – Comparison of the Non-Linear and Simplified Linear Analysis Methods

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