CEE385 Performance-Based Earthquake Engineering

Final report: matlab graphic user interface for performance assessment

Ji Su Lee
Wenjin Situ

1 Introduction

This report introduces a graphic user interface (GUI) that allows for a thorough performance assessment of a building. The GUI was programmed in MATLAB, and is laid out in a sequential order that corresponds to the performance-based earthquake engineering frame:

$$v(DV) = \int\int\int G(DV|DM)\ |dG(DM|EDP)|\ |dG(EDP|IM)|\ d\lambda(IM)$$

where the variables are decision variable (DV), damage measure (DM), engineering demand parameter (EDP), and intensity measure (IM).

The following section outlines the performance assessment process in sequential form and uses files uploaded to the course Canvas website for the December 7th (Wednesday) set of presentations. Throughout the report, there are comments made on the resulting figures. The report concludes with commentary regarding options for further improvement as well as an in-depth discussion on the impact of performance-based earthquake engineering.

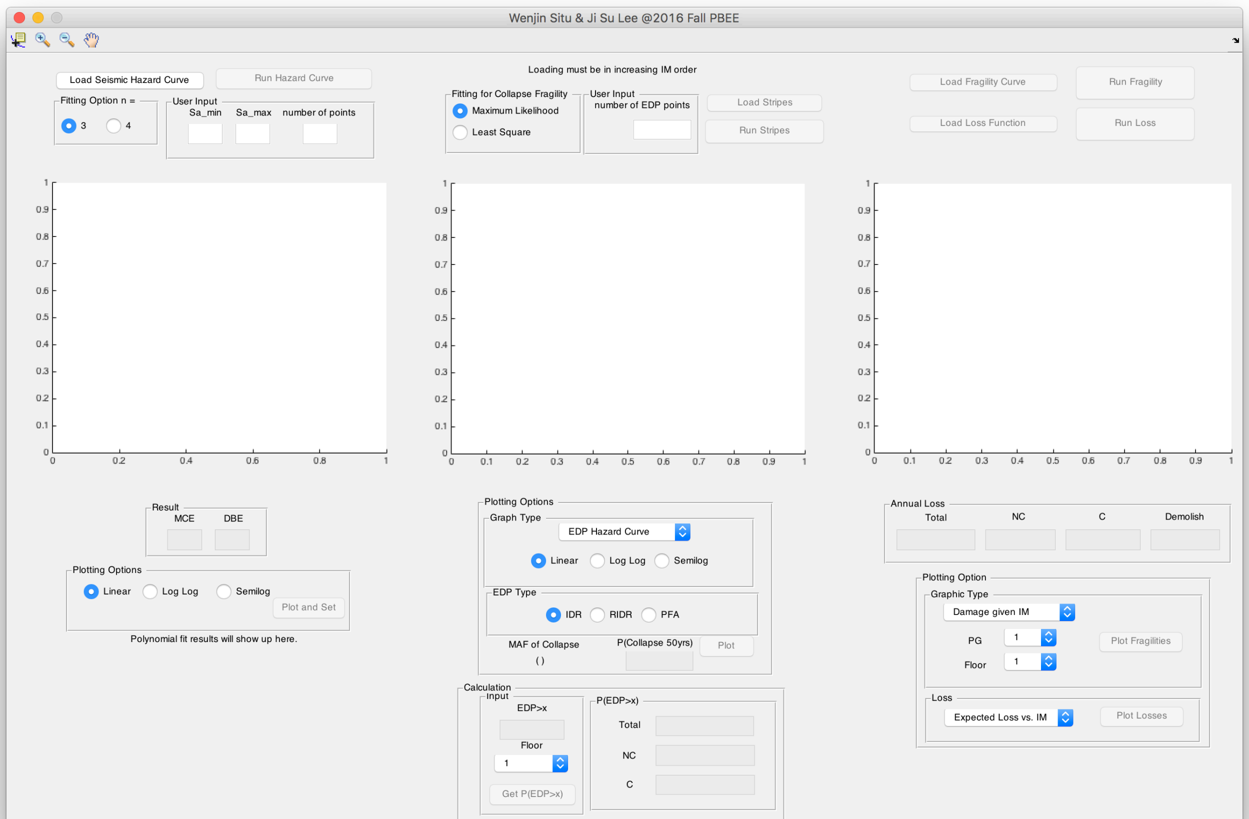


Figure 1. Overall GUI layout

The user can use the zoom in/out and data cursor tool bar in the top left corner to look at any of the plots in detail as shown in Figure 2.

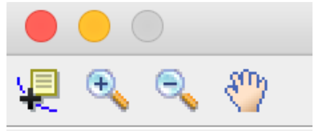
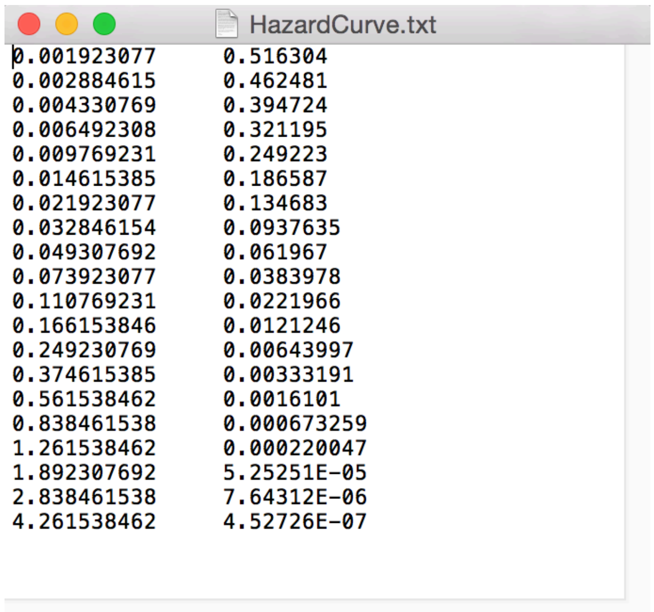


Figure 2. Graph tool bar

2 Intensity Measure

First the user is asked to load a seismic hazard curve (SHC). The GUI accepts files in .txt form of the layout shown in Figure 3:



HazardCurve.txt

0.001923077	0.516304
0.002884615	0.462481
0.004330769	0.394724
0.006492308	0.321195
0.009769231	0.249223
0.014615385	0.186587
0.021923077	0.134683
0.032846154	0.0937635
0.049307692	0.061967
0.073923077	0.0383978
0.110769231	0.0221966
0.166153846	0.0121246
0.249230769	0.00643997
0.374615385	0.00333191
0.561538462	0.0016101
0.838461538	0.000673259
1.261538462	0.000220047
1.892307692	5.25251E-05
2.838461538	7.64312E-06
4.261538462	4.52726E-07

Figure 3: Required format for the seismic hazard curve .txt file

where the first column represents the spectral acceleration in units of gravitational acceleration and the second column represents the corresponding annual frequency of exceedance (AFE).

The user may then select the option to fit a third- or fourth-order polynomial to the original SHC, which is then fitted at regular logarithmic intervals. Regardless of the user's choice in this portion of the GUI, the "Run" button will fit both third- and fourth-order polynomials to the original SHC and display the resulting polynomial equations (along with the respective R^2 values) on the GUI. Then, after viewing the goodness of fit for both polynomials, the user may modify their original selection and click "Plot & Set" to update their fitting choice. This choice will be used for integration with the later portions of the GUI, including the EDP hazard curve, collapse deaggregation, and calculation of loss. The "Plot & Set" option can also be used to reset the axes setting to linear, log-log, or semi-log scales.

The user also has the option to specify a maximum Sa value for the polynomial fit to extrapolate to. This value may extend beyond the limit of the original seismic hazard curve file. This will become more important as we consider collapse deaggregation (see Section 3.4). **The default Sa range used was from 0.8 times the minimum of the original Sa value to 3g, with 100 log space data points.**

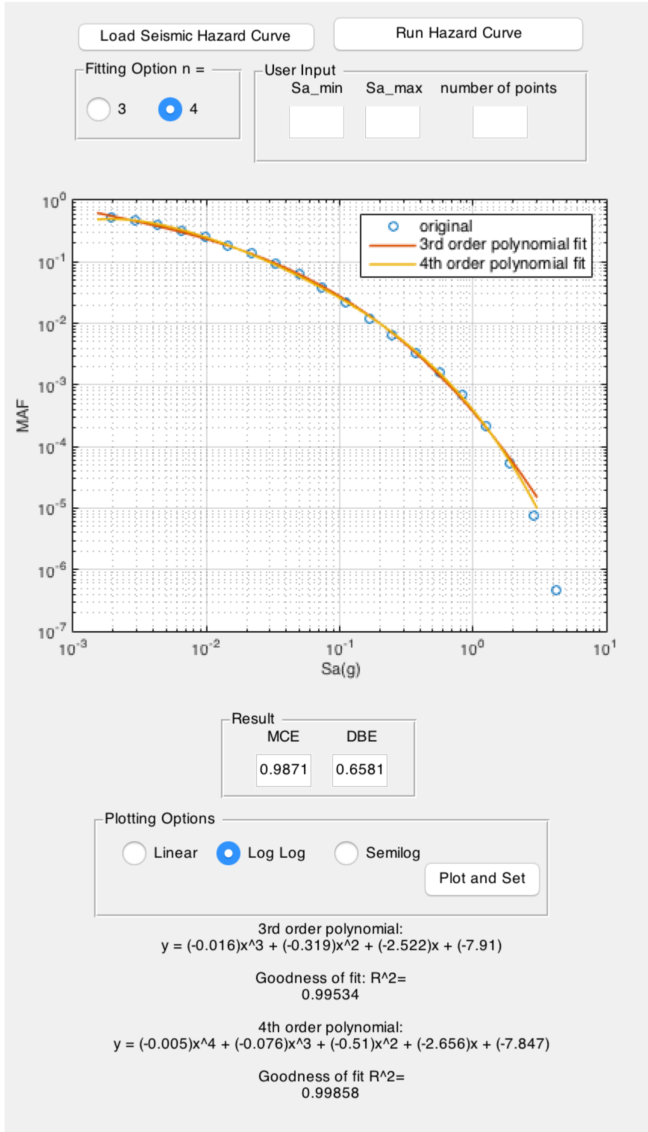


Figure 4: Original seismic hazard curve, with the 3rd and 4th order polynomial fitted seismic hazard curves

For this case study, we use the 4th order polynomial as it as a higher goodness of fit value. In fact, it is also a better match for the original SHC than the 3rd order polynomial at both the lower IM values (higher probability of occurrence) and the higher IM values (higher collapse probability and larger median EDP values).

The MCE level earthquake and the DBE level earthquake can also be interpolated from the chosen polynomial fit by solving for MAF of 2% in 50 years (MCE level) and 2/3 of the Sa_{MCE} level (DBE level). We have the option to solve for the DBE level earthquake by solving for MAF of 10% in 50 years, but such analysis may yield a low value for the DBE earthquake if the seismic hazard curve is steep. Thus, we use the MCE level earthquake as the baseline and apply a 2/3 factor to make a conservative estimate for the DBE level earthquake. **For this particular seismic hazard curve, the MCE level ground motion is 0.9871g and the DBE level ground motion is 0.6581g.**

3 Engineering demand parameter

The user may now select stripe analysis data (one file per stripe) to be added to the GUI database, with the “Load Stripes” button, as shown in Figure 5. The stripe files must be uploaded in order of increasing IM levels. After each upload, the IM levels of each uploaded file is shown in a pop-up dialog window. The user can also choose either maximum likelihood method or least square method for fitting the collapse fragility curve. In this analysis, the maximum likelihood method is used.

The maximum EDP used to compute EDP hazard are:

$$\mathbf{IDR_{max} = 0.1}$$
$$\mathbf{PFA_{max} = 2.5}$$
$$\mathbf{RIDR_{max} = 0.05}$$

The user can input number of EDP points to use; **the default value is 100 points, spaced linearly.**

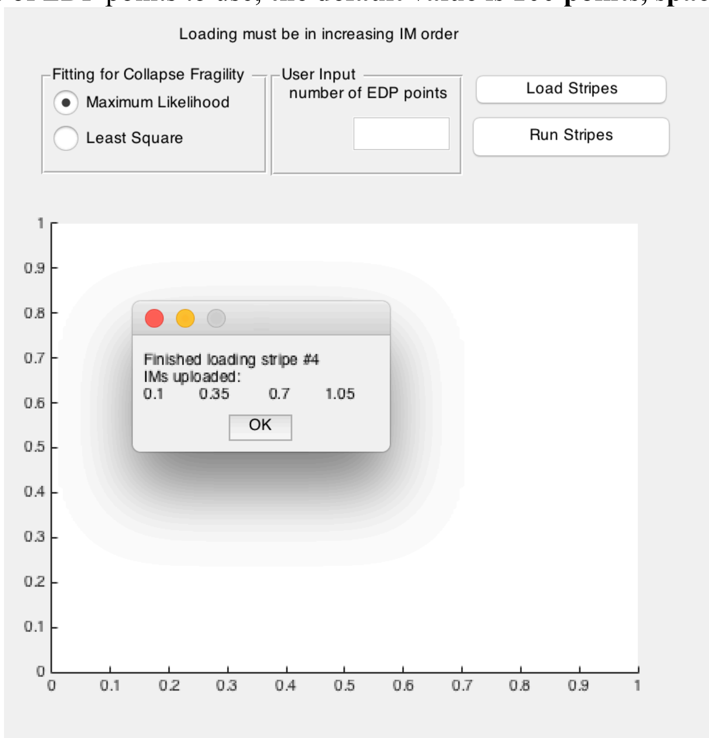


Figure 5: The "Load Stripes" button allows for browsing and loading stripe analysis files (.csv file format) to the GUI database. The "Run Stripes" button will analyze the stripe results and fit a collapse fragility curve using the user-selected option for fitting.

The stripe analysis files must be in the format shown below in Figure 6, with each row showing the numerical result for each EDP value of interest. The first two columns represent the EDP type and corresponding story/floor. The first cell (row 1, column 1) contains the IM value.

	A	B	C	D	E	F	G	H	I	J
1	Sa=0.10	Story/Floor	RSN6906_DA	RSN4856_CH	RSN1529_CH	RSN825_CAP	RSN4896_CH	RSN4896_CH	RSN5657_IW	RSN1063_NC
2	IDR	1	0.0022465	0.0023139	0.0022237	0.002451	0.0024602	0.0023777	0.002018	0.0022504
3	IDR	2	0.0030037	0.0029328	0.0029357	0.0032129	0.0031784	0.0030261	0.0028007	0.0029802
4	IDR	3	0.0026529	0.0026479	0.00253	0.0030096	0.0026891	0.0026046	0.003	0.002739
5	IDR	4	0.0023607	0.0023454	0.0021178	0.0025677	0.0021773	0.0021721	0.0028173	0.0024373
6	IDR	5	0.0017934	0.0016224	0.0014955	0.0020416	0.0014787	0.0015191	0.002095	0.0018591
7	IDR	6	0.001045	0.00088809	0.00083585	0.0017976	0.00086578	0.00082962	0.0012022	0.001122
8	RIDR	1	5.21E-07	5.50E-06	1.82E-05	2.96E-05	2.63E-05	6.78E-05	1.14E-08	3.59E-05
9	RIDR	2	7.07E-07	7.34E-06	2.44E-05	3.95E-05	3.53E-05	9.09E-05	1.43E-08	6.49E-05
10	RIDR	3	6.25E-07	6.36E-06	2.14E-05	3.43E-05	3.10E-05	7.95E-05	1.22E-08	7.59E-05
11	RIDR	4	5.30E-07	5.26E-06	1.80E-05	2.90E-05	2.62E-05	6.70E-05	1.01E-08	7.95E-05
12	RIDR	5	3.70E-07	3.59E-06	1.25E-05	2.04E-05	1.84E-05	4.67E-05	6.97E-09	6.24E-05
13	RIDR	6	1.99E-07	1.90E-06	6.68E-06	1.06E-05	9.90E-06	2.52E-05	3.74E-09	3.43E-05
14	PFA	1	0.057901	0.068728	0.038158	0.28553	0.05653	0.04823	0.1438	0.060886
15	PFA	2	0.055965	0.067147	0.04338	0.24821	0.066722	0.06056	0.10159	0.072598
16	PFA	3	0.0763	0.090464	0.062918	0.181	0.097394	0.080636	0.10949	0.083479
17	PFA	4	0.099929	0.10268	0.084347	0.16052	0.12176	0.09331	0.13171	0.095047
18	PFA	5	0.1118	0.10946	0.099871	0.23269	0.11952	0.10422	0.13182	0.1217
19	PFA	6	0.12709	0.1273	0.10878	0.16051	0.11511	0.11236	0.16211	0.12785
20	PFA	7	0.15248	0.13424	0.12553	0.26854	0.13062	0.12233	0.18216	0.16869

Figure 6: Required format of stripe analysis data. The file is a .csv file.

Then, once all available stripe analysis files have been uploaded, the user may press "Run Stripes". This button will analyze the stripe files and calculate a collapse fragility curve using the user-specified fitting option shown in Figure 5. The "Run Stripes" button will also calculate the EDP hazard curve for each type of EDP of interest. The polynomial fitted seismic hazard curve will be used to calculate the EDP hazard curve.

Once the analysis is completed, a dialog window will pop up saying "Analysis Completed!". The MAF of collapse will automatically be updated below the EDP axes (see Figure 7). For this dataset, **the mean annual frequency of collapse appears to be 0.06%, and the probability of collapse in 50 years is about 3%.**

Figure 7 shows the IDR hazard curve for the dataset.

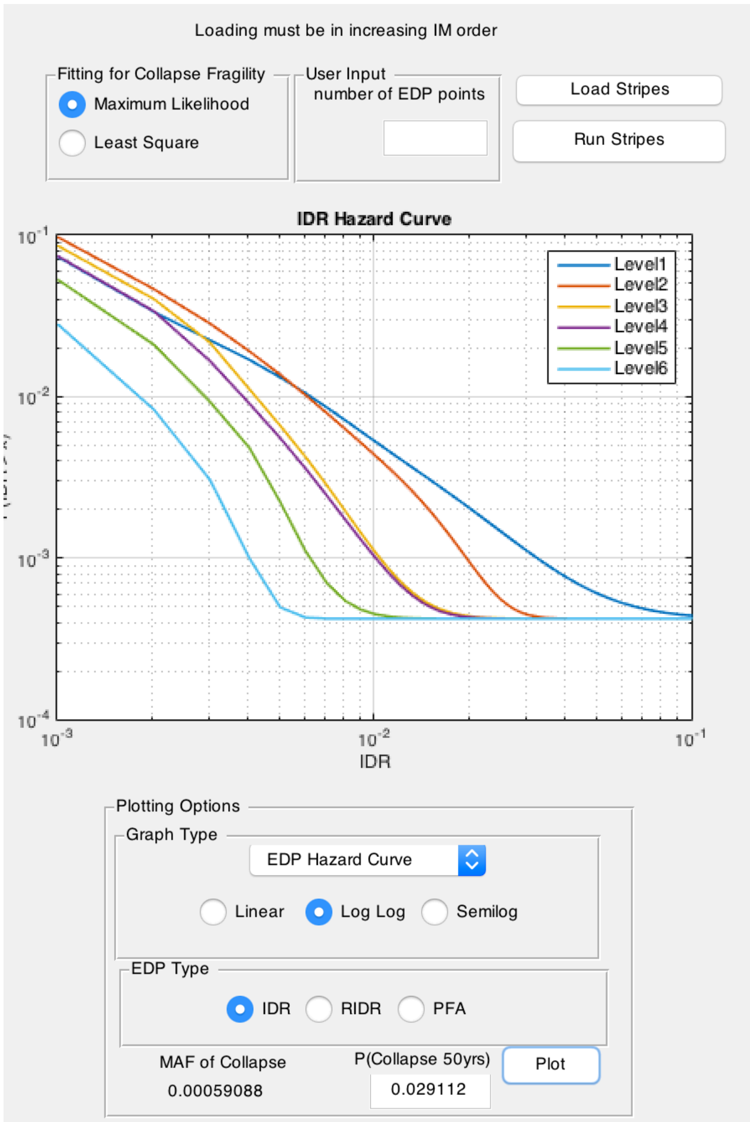


Figure 7: The resulting figure for the EDP hazard curve, using IDR as the EDP

Then, the user may select options from the "Plotting Options" panel to select which EDP they want to view and the kind of plot they want to view. In the graph type option, there are five options available. An example of each kind is shown in Section 3.1.

3.1 EDP Hazard Curve

The EDP Hazard Curves for IDR, RIDR, and PFA are shown in this section in Figure 8, Figure 9, and Figure 10, respectively.

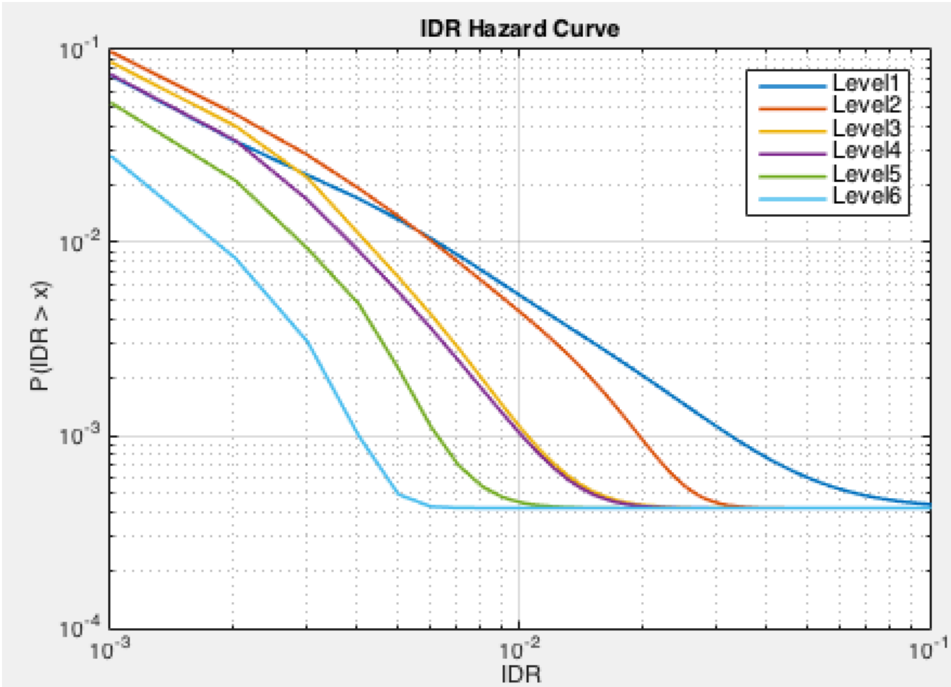


Figure 8: IDR Hazard Curve

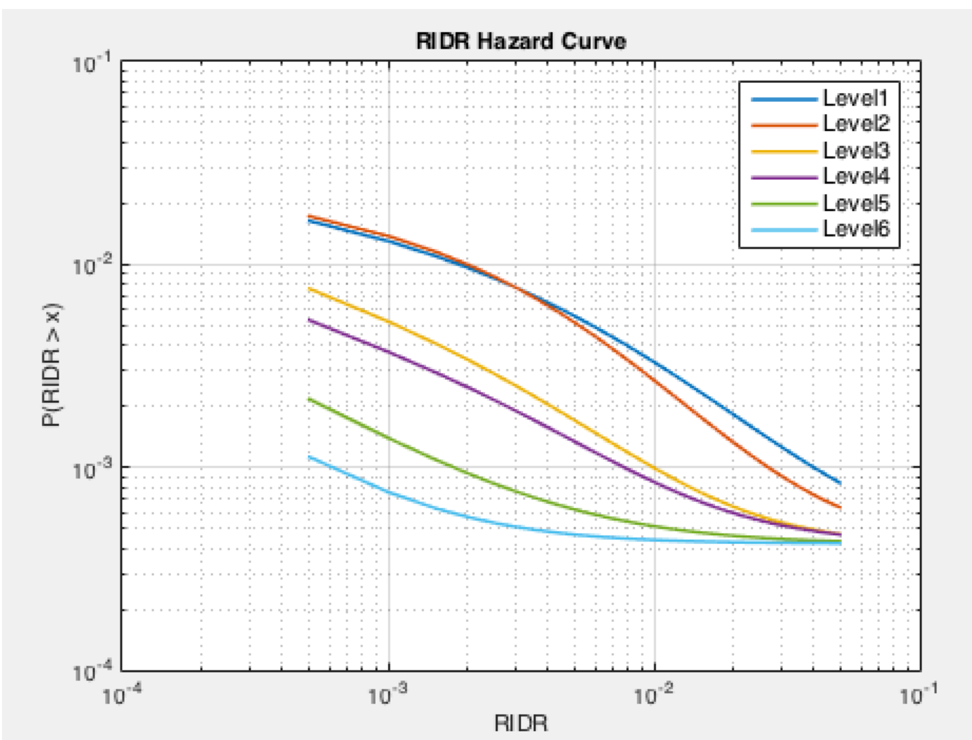


Figure 9: RIDR Hazard Curve

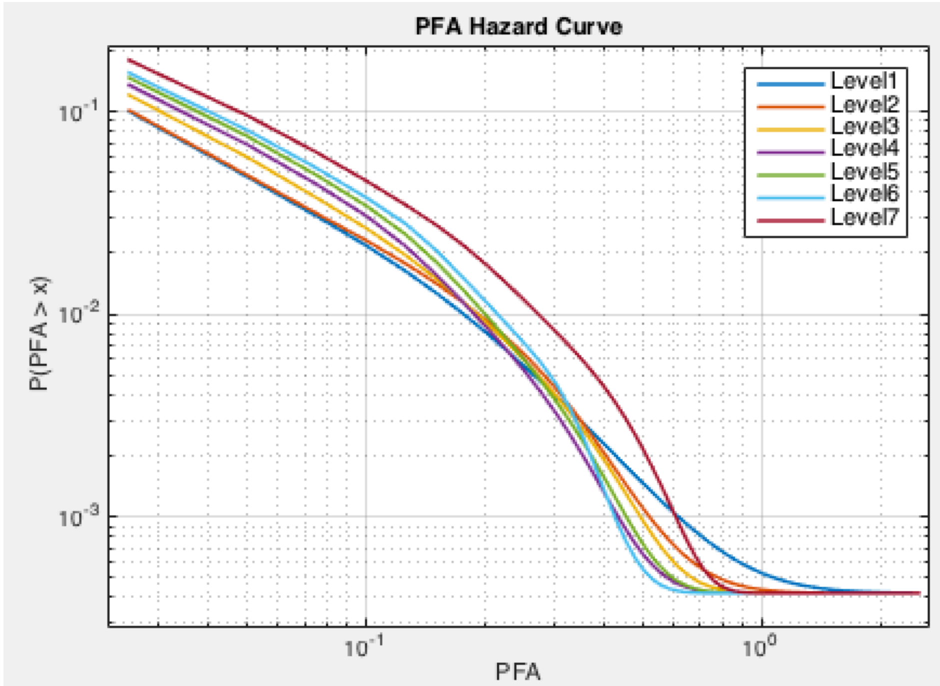


Figure 10: PFA Hazard Curve

The user can calculate the probability of EDP exceedance with the Get P(EDP>x) bottom. The program will then interpolate in the EDP hazard curve with log-log scale to obtain the probability. Figure 11 demonstrates the probability calculated of **P (IDR > 0.01) of first floor to be 0.0053**. It can be verified by zooming in the graph as shown in Figure 12.

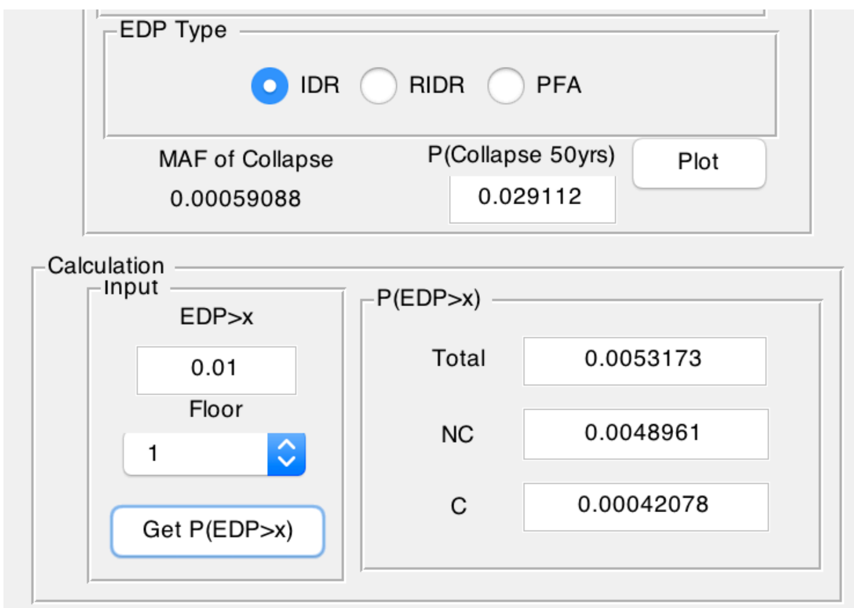


Figure 11: P(IDR > 0.01) of first floor

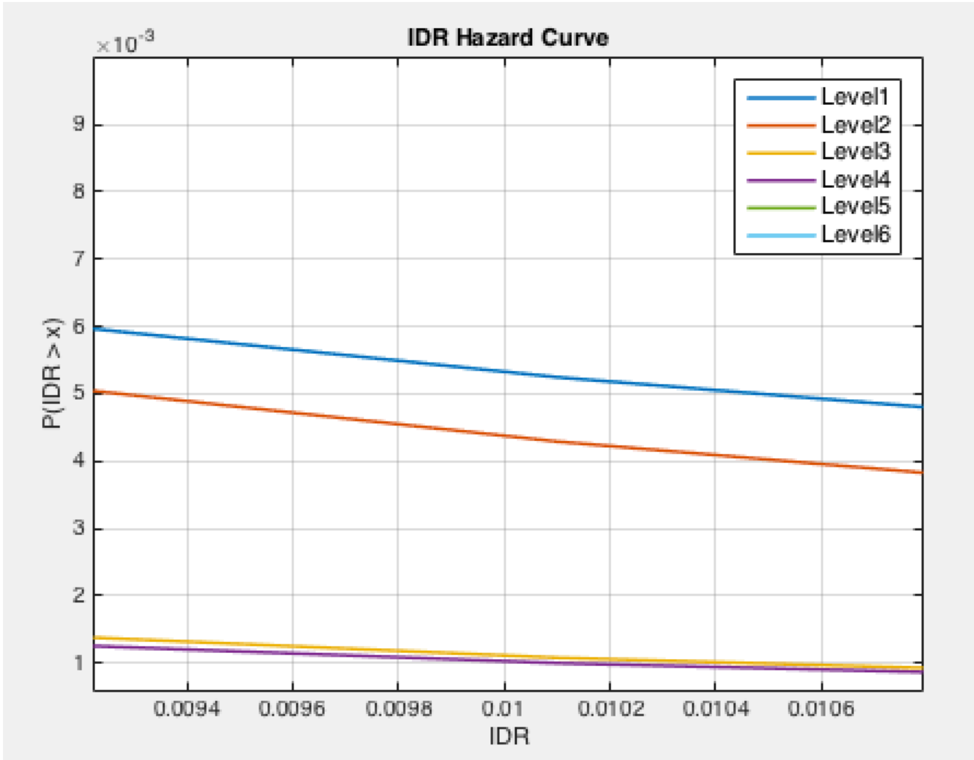


Figure 12: Zoomed in P(IDR > x) graph

3.2 Stripe Median Plots

Figure 13 shows a sample “Stripe Median” plot, which plots the EDP of interest on the y-axis and the IM values on the x-axis. Although there are limited numbers of stripe analysis files (and thus a limited number of IM levels), the data is interpolated between each IM level available. Beyond the largest IM level that is available in the stripe analysis files, the slope of the last median(EDP) vs. IM data points are used to extend the line beyond the maximum IM available. The MATLAB function geomean is used to compute the medians.

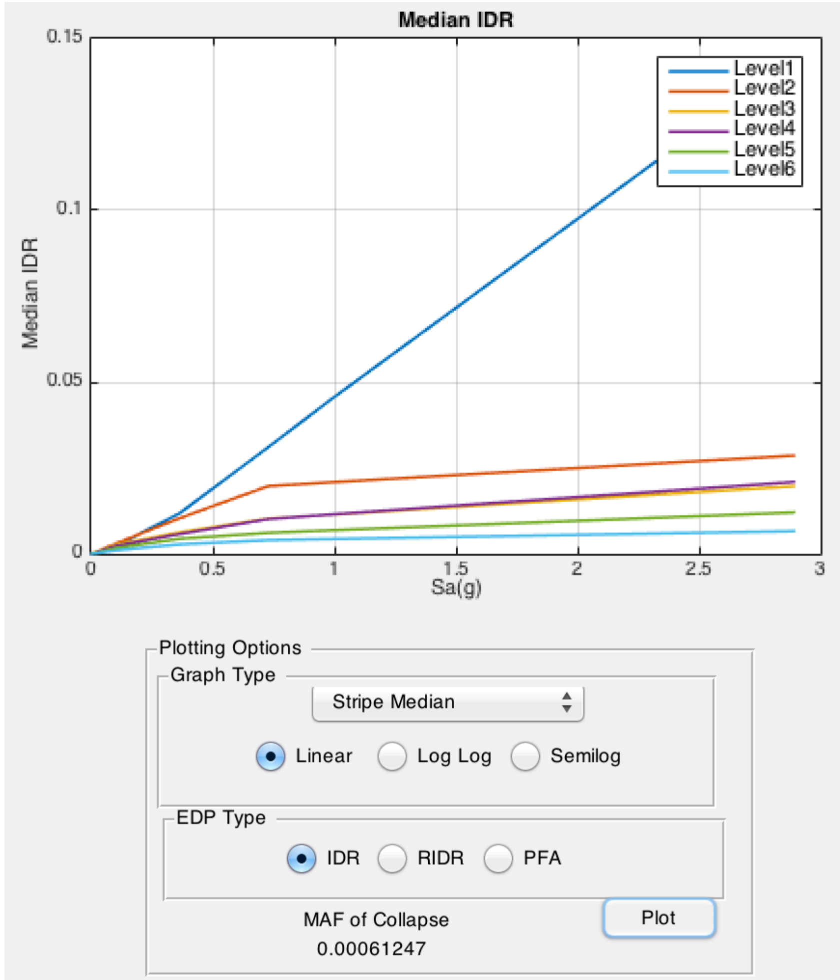


Figure 13: Plotting Median IDR vs. IM for each story

More specifically, Figure 13 shows the median IDR for each story in the building. A zoomed in view of the median IDR plot is shown in Figure 14. This view is limited to the IM values that are extracted directly from the stripe files, and shows more clearly that the median IDR decreases with story height.

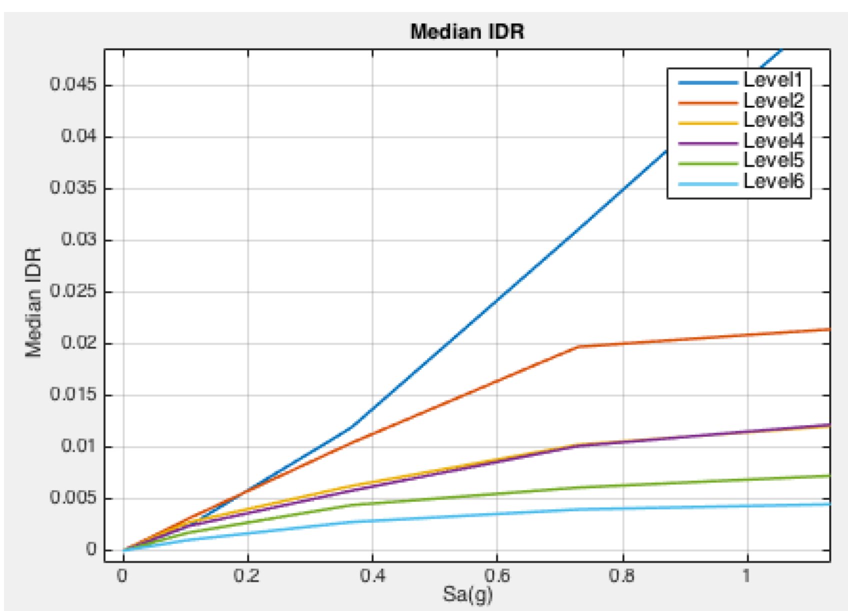


Figure 14: Zoomed in view of median IDR vs. Sa, for IM = 0 to IM = maximum IM values in the stripe files

The median IDR tends to increase with increasing Sa levels. In additional, the median IDR decreases with increasing floor levels: level 1 has the greatest median and level 6 has the least median.

Figure 15 and Figure 16 show the median RIDR and PFA per each story/floor, respectively. These figures show the stripe analysis results for the entire range available (as a function of the maximum IM value from the interpolated seismic hazard curve of Section 2).

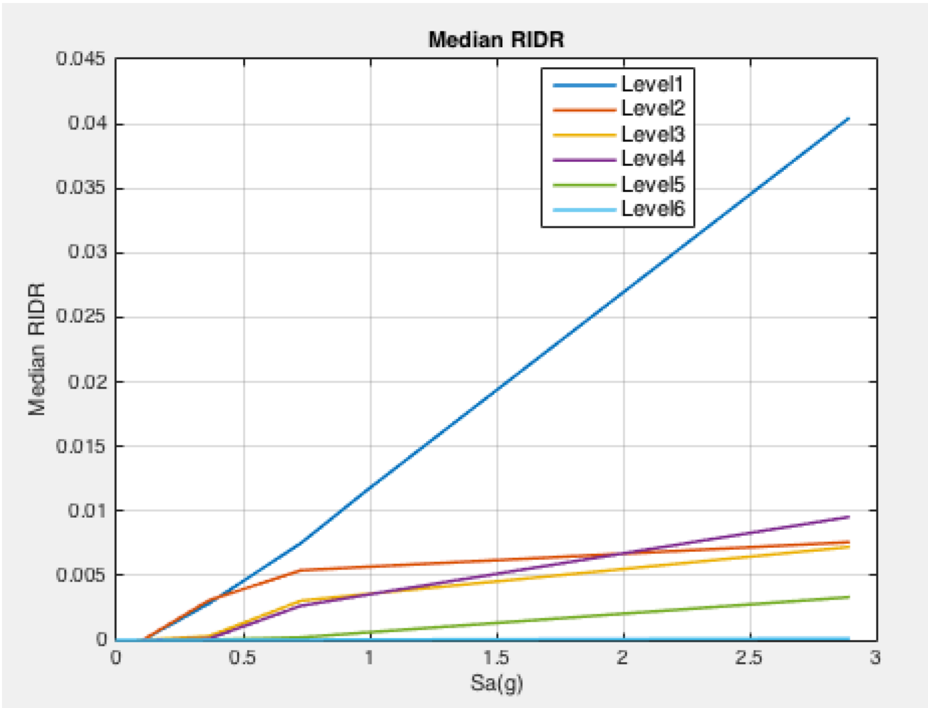


Figure 15: Plotting Median RIDR vs. each story

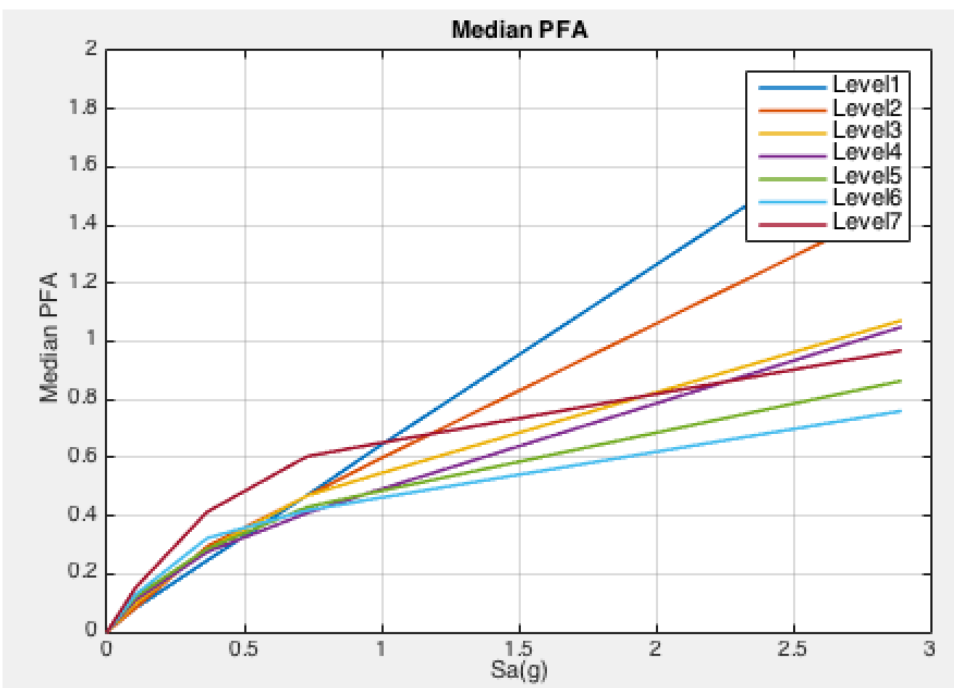


Figure 16: Plotting Median PFA vs. each floor

To investigate trends more closely, similar to Figure 14, Figure 17 and Figure 18 show the median values of RIDR and PFA, respectively, for the range of IM values available in the stripe analysis files. This allows us to interpret what the stripe files reveal about median EDP values across different IM's and floors.

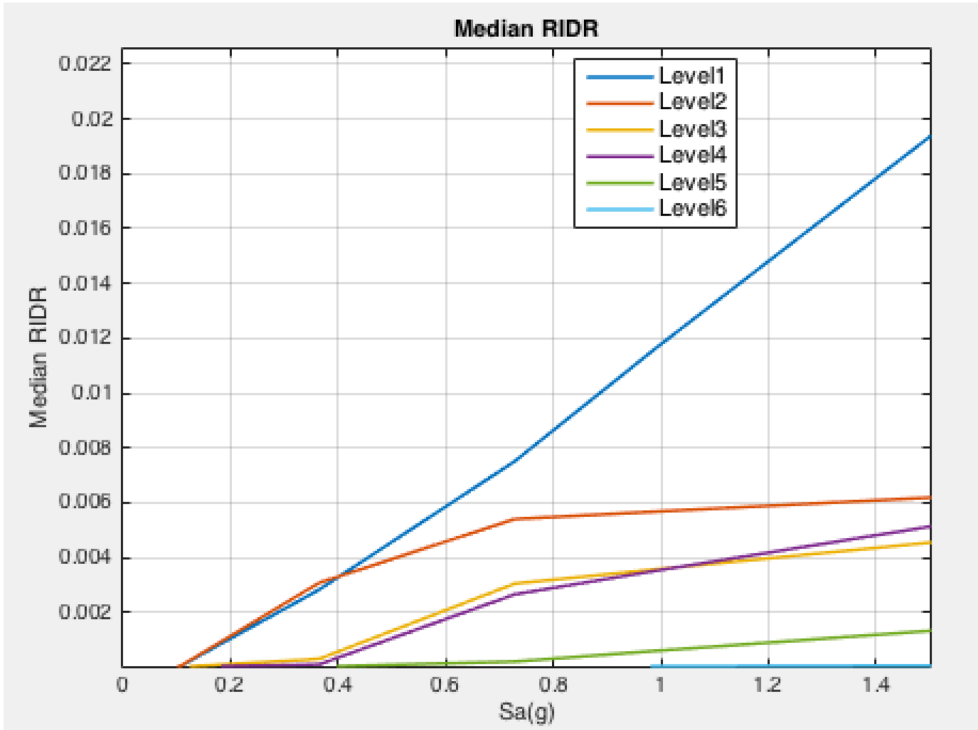


Figure 17: Zoomed in view of median RIDR vs. Sa, for IM = 0 to IM = maximum IM values in the stripe files

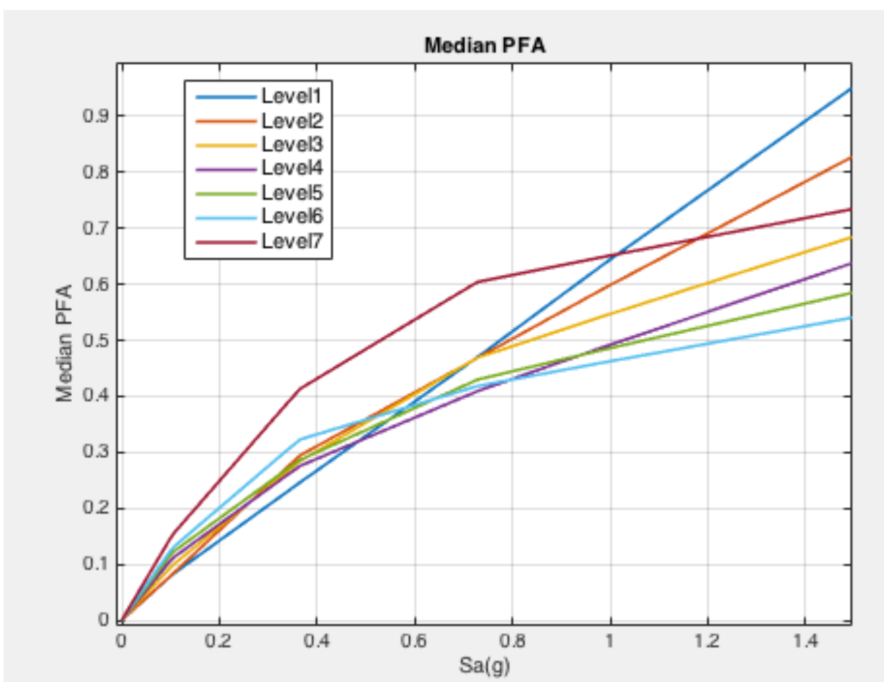


Figure 18: Zoomed in view of median PFA vs. Sa, for IM = 0 to IM = maximum IM values in the stripe files

As shown above, the roof has the greatest median PFA among all levels for ground motion lower than 1g. After 1g, the median PFA of the first floor starts to dominate.

The plots shown in this section reveal a great deal of information for the building owners, particularly for the placement of nonstructural components whose damage fragility curves may be based on any of the EDP parameters shown here. For example, if a nonstructural component whose replacement cost is tens of thousands of dollars, then it would be wise of the engineer to suggest that the placement of said nonstructural component be on a floor with the smallest median value for the relevant engineering demand parameter. The engineer should also factor in the structural integrity of the floor so that falling walls or ceilings would be least likely to damage said component. This kind of understanding would help ensure the smallest annual loss from that nonstructural component.

3.3 Stripe Logarithmic Standard Deviation Plots

The third dropdown menu option for analyzing stripe data is "Stripe LogStd" plot, which plots the logarithmic standard deviation of the EDP of interest on the y-axis and the corresponding IM on the x-axis. Unlike the stripe median values, for IM values beyond the maximum IM level extracted directly from the stripe analysis files, the logarithmic standard deviation values are extended as a constant beyond said maximum IM. The value of this constant is the logarithmic standard deviation of the maximum IM available from the stripe analysis files.

Figure 19, Figure 20, and Figure 21, respectively, show the logarithmic standard deviation of IDR, RIDR, and PFA as they vary as a function of IM.

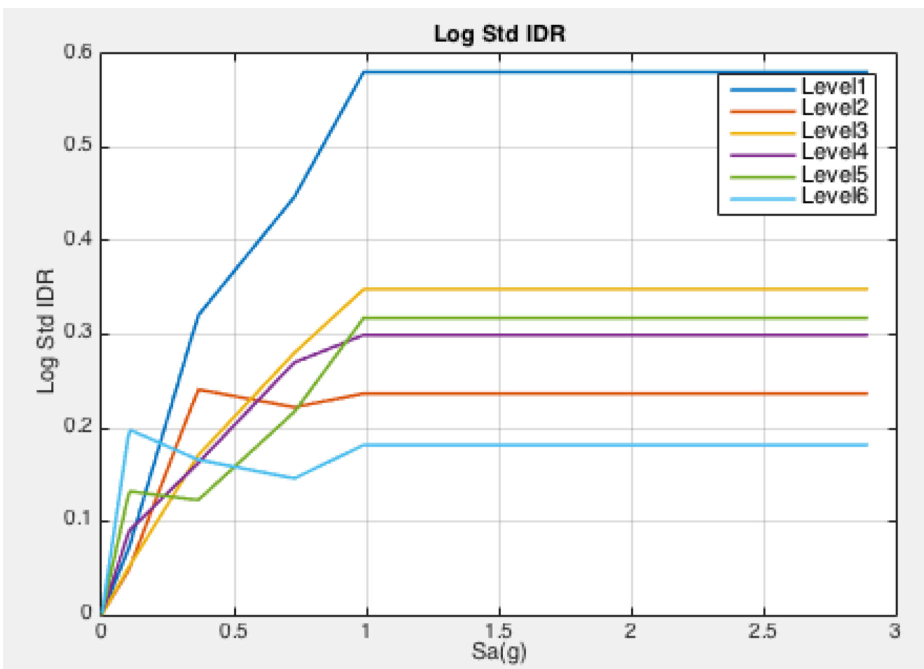


Figure 19: Logarithmic Standard deviation of IDR vs. IM

From Figure 19, only the log standard deviation of level 1 increases with increasing Sa, while for other levels they converge to a constant rate beyond Sa value about 1g.

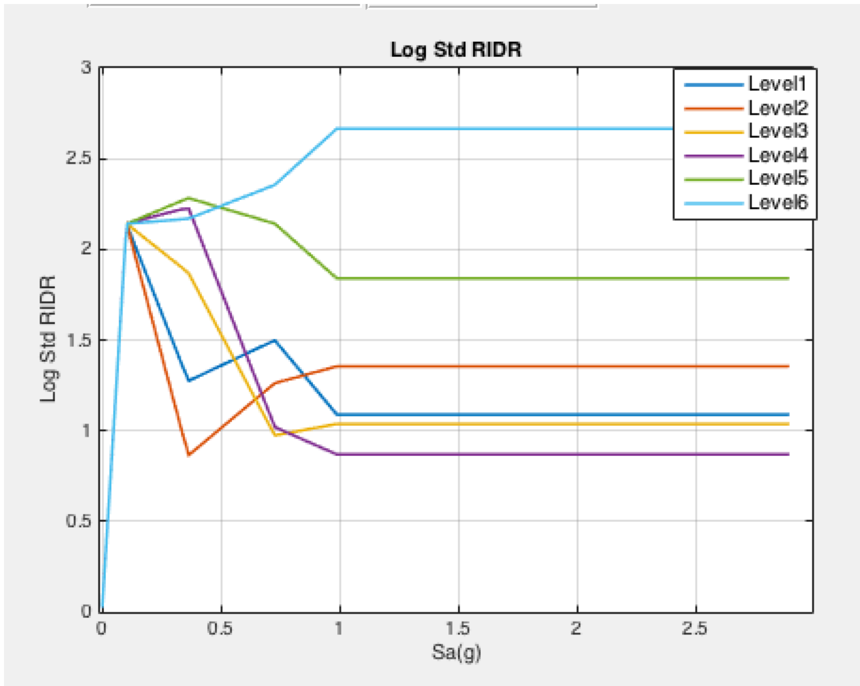


Figure 20: Logarithmic Standard Deviation of RIDR vs. IM

Figure 20 shows that the log standard deviation of RIDR is the greatest among the 3 EDP interests. For the first stripe level Sa = 0.1g, the standard deviations of all floors are about 2. The values then start to fluctuate to a great degree with increasing spectral acceleration levels.

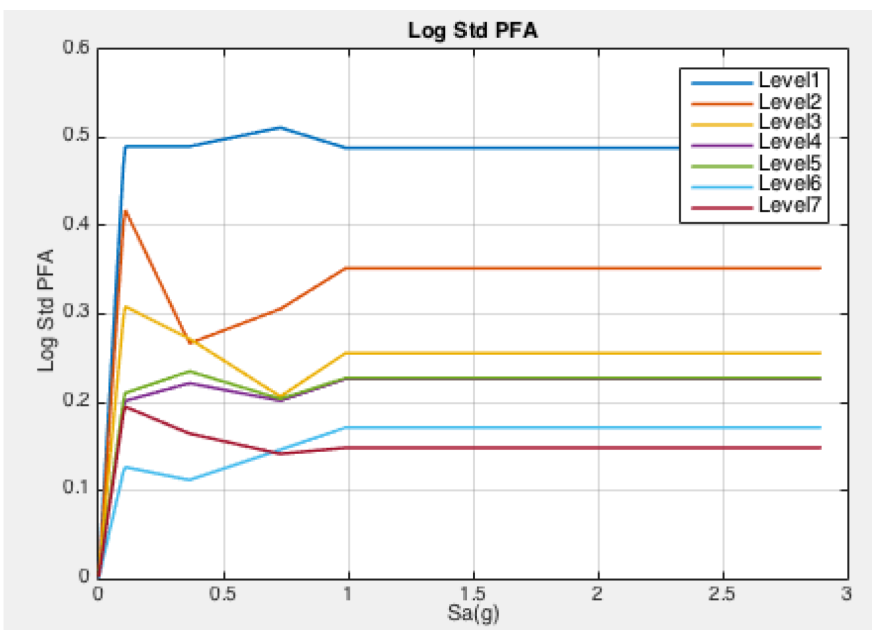


Figure 21: Logarithmic standard deviation of PFA vs. IM

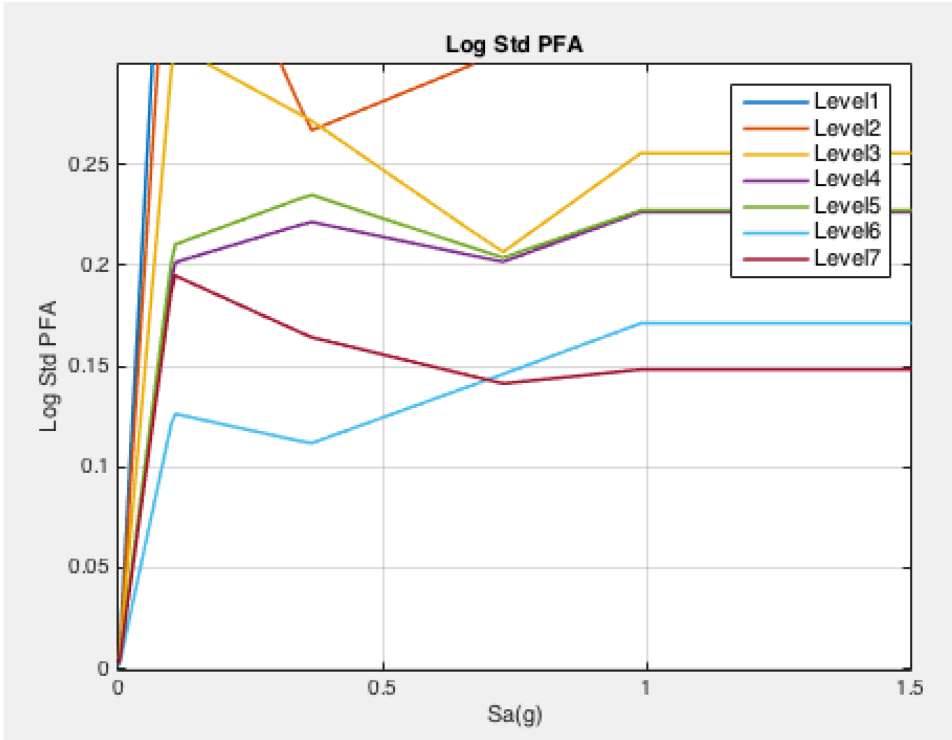


Figure 22. Logarithmic standard deviation of PFA vs. IM (zoomed in)

It can be seen from Figure 21 that the logarithmic standard deviation of the PFA—a measure of variation of PFA across different IM's decreases with higher levels. It seems that level 1 has the highest dispersion in its PFA values across different IM's. In other words, the variability of the PFA on the higher floors is much less and thus PFA is much more predictable on the higher floors. The placement of PFA-sensitive components within a building (especially nonstructural components that are costly and experience damage at much lower EDP-values—should factor in not only the median PFA values but also the variability of PFA.

3.4 Collapse Fragility Curve

Figure 23 shows a collapse fragility curve that is created by choosing Graph Type as "Collapse Fragility". The lognormal parameters that were used to fit the collapse fragility curve are shown, and the original data points that are used for fitting are shown on the plot as well. The user has the option of choosing the maximum likelihood method or the least squares method for fitting the collapse fragility curve, as was shown in Figure 5. If the user wishes to use a different method after viewing the resulting collapse fragility curve, he or she may change the fitting option and click "Run Stripes" to re-generate the desired collapse fragility curve.

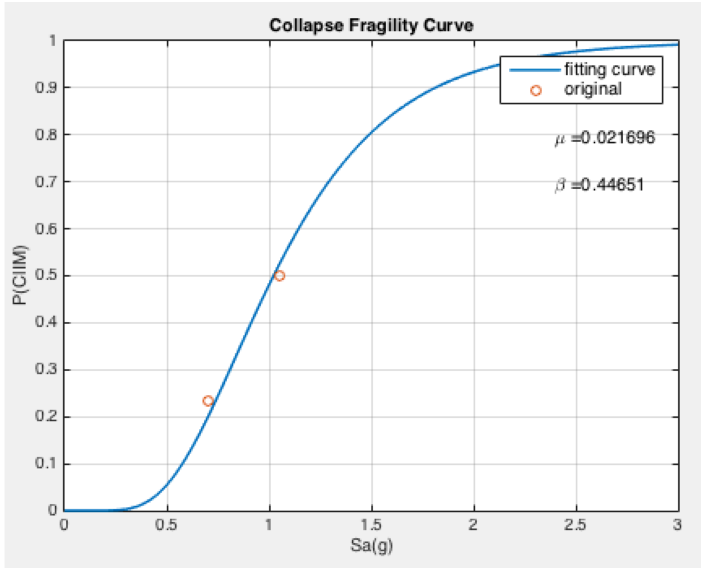


Figure 23: Collapse Fragility Curve, created with the Maximum Likelihood Method

For this building, the median IM for collapse is at approximately S_a = 1.0g. This means that at Sa = 1.0g, there is a 50% probability of collapse in the structure.

Figure 24 shows the collapse deaggregation, or how the contribution to the total probability of collapse is arranged among the different intensity measure values. As expected, the largest contribution to the probability of collapse stems from the lower spectral acceleration values. This is because while the probability of collapse at those spectral acceleration values may be low, the likelihood of occurrence of those spectral acceleration values are much larger than the high IM values that have higher probabilities of collapse.

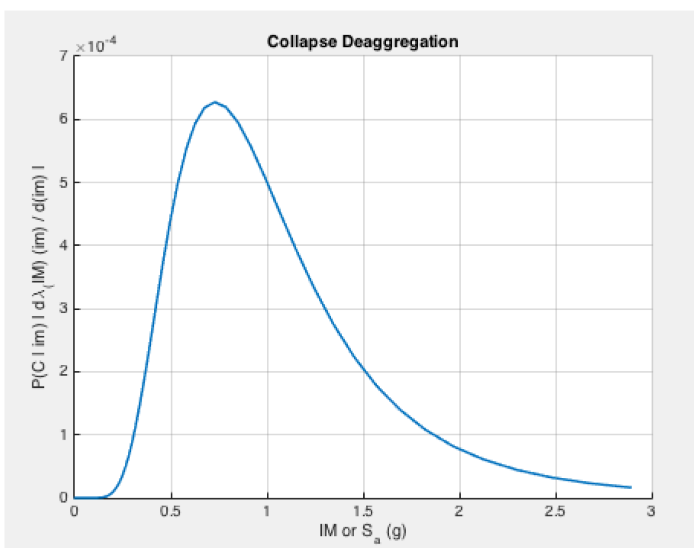


Figure 24: Collapse Deaggregation

The collapse deaggregation curve is critical for the user in determining whether or not the polynomial fit seismic hazard curve extends to a large enough IM value. For example, Figure 24, at nearly 3.0g, the contribution to the collapse deaggregation is not yet at zero. Thus, the user may wish to return to the SHC portion of the GUI and select a larger maximum IM value for interpolation and to ensure that the contribution to collapse deaggregation at that maximum IM is indeed zero. For demonstration, Figure 25 and Figure 26 show the seismic hazard curve and collapse deaggregation curve after we extend the maximum ground motion intensity to be 4.0g.

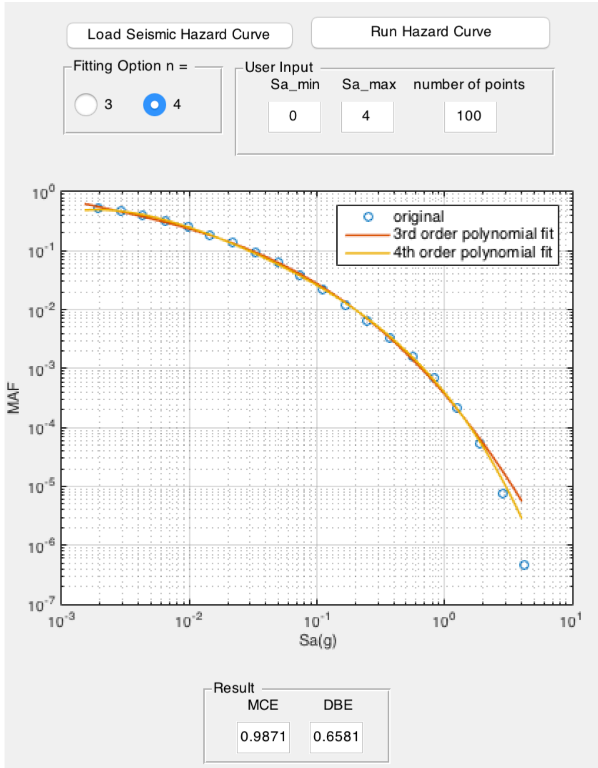


Figure 25. Adjusted Seismic Hazard Curve for Sa_{max} = 4.0g

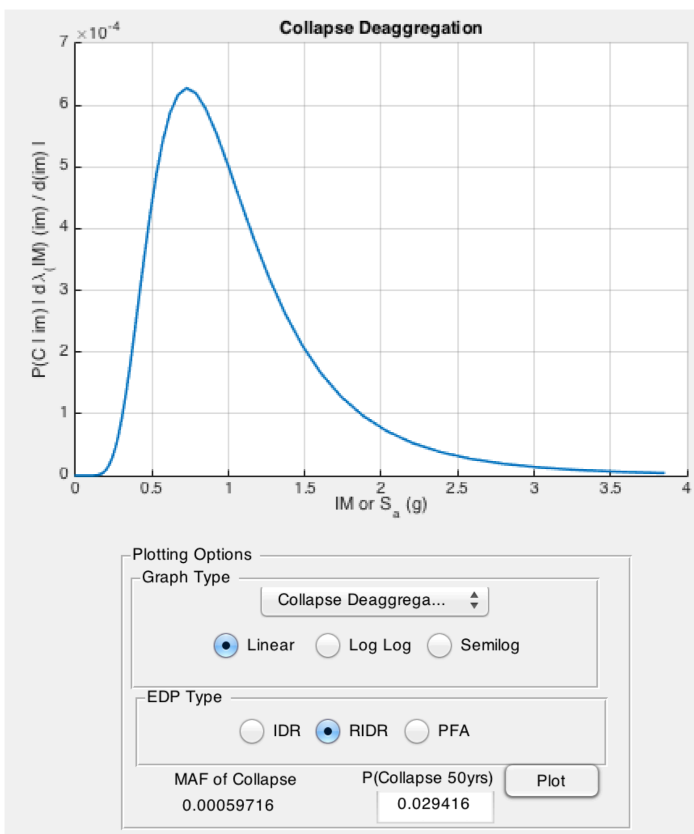


Figure 26. Adjusted Collapse Deaggregation Curve for Sa_{max} = 4.0g

Note that the mean annual frequency of collapse and the probability of collapse in 50 years has been updated to the numbers shown in the above figure. Since only the midpoints of the seismic hazard curve are used for the calculation of deaggregation (for the slope of the seismic hazard curve), the maximum Sa will not reach the Sa_{max} specified.

4 Damage Measure

The user may now select fragility curves to calculate the damage expected at a certain EDP or IM. The fragility curve file may be selected using the "Load Fragility" button that becomes available once the EDP files have all been loaded and analyzed. The fragility curve file format should follow the file format shown in Figure 27:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	PG	EDP_Type	DS1_Fra_Me	DS1_Fra_LnS	DS2_Fra_Me	DS2_Fra_LnS	DS3_Fra_Me	DS3_Fra_LnS	DS1_Loss_M	DS1_Loss_Ln	DS2_Loss_M	DS2_Loss_Ln	DS3_Loss_M	DS3_Loss_LnStDev
2	PG1	IDR	0.014	0.33	0.027	0.36	0.055	0.3	180	0.4	380	0.4	860	0.55
3	PG2	IDR	0.019	0.33	0.035	0.36	0.055	0.3	250	0.4	450	0.4	860	0.55
4	PG3	IDR	0.0026	0.43	0.0051	0.4	0.016	0.4	120	0.35	450	0.45	882	0.5
5	PG4	IDR	0.008	0.43	0.012	0.42	0.021	0.45	260	0.35	550	0.45	882	0.5
6	PG5	PFA	0.7	0.42	1	0.38	1.96	0.42	150	0.4	450	0.45	882	0.5
7	PG6	PFA	0.95	0.45	1.25	0.38	2.4	0.42	250	0.4	550	0.45	882	0.5

Figure 27: Sample file for fragility curve information, in .csv form

There are 4 plots that become available once the fragility curves have been analyzed as shown in Figure 28.

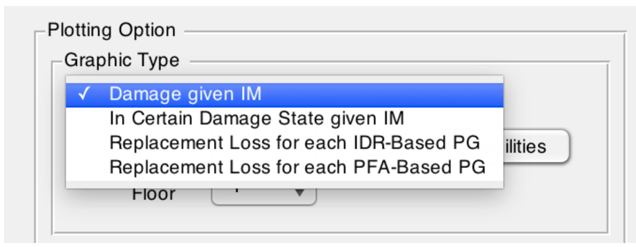


Figure 28: Plotting Options for Fragility Data

4.1 Damage Fragility Curves

This section shows the fragility curves for each performance group, calculated using the lognormal cumulative distribution function. It should be noted that PG1-4 are IDR based, while PG5-6 are PFA based.

We note that the damage fragility curves of Figure 31 and Figure 32 (performance groups 3 and 4) reach 100% probability of being in damage state 3 at the lowest EDP compared to the fragility curves of Figure 29 and Figure 30 (performance groups 1 and 2). PG 3 and 4 represent nonstructural components, which confirms the general trend that nonstructural components tend to be damaged at lower EDP values compared to structural components. Thus, we will later see in the loss calculations of Figure 52 that PG 3 and 4 contribute the most to annual loss calculations.

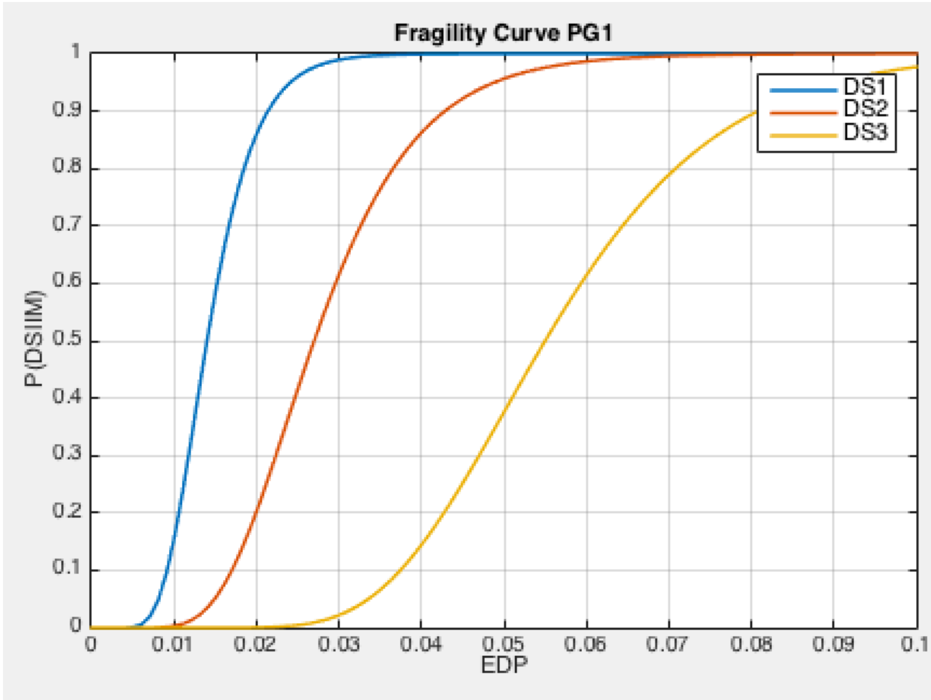


Figure 29: Damage Fragility Curve for Performance Group 1

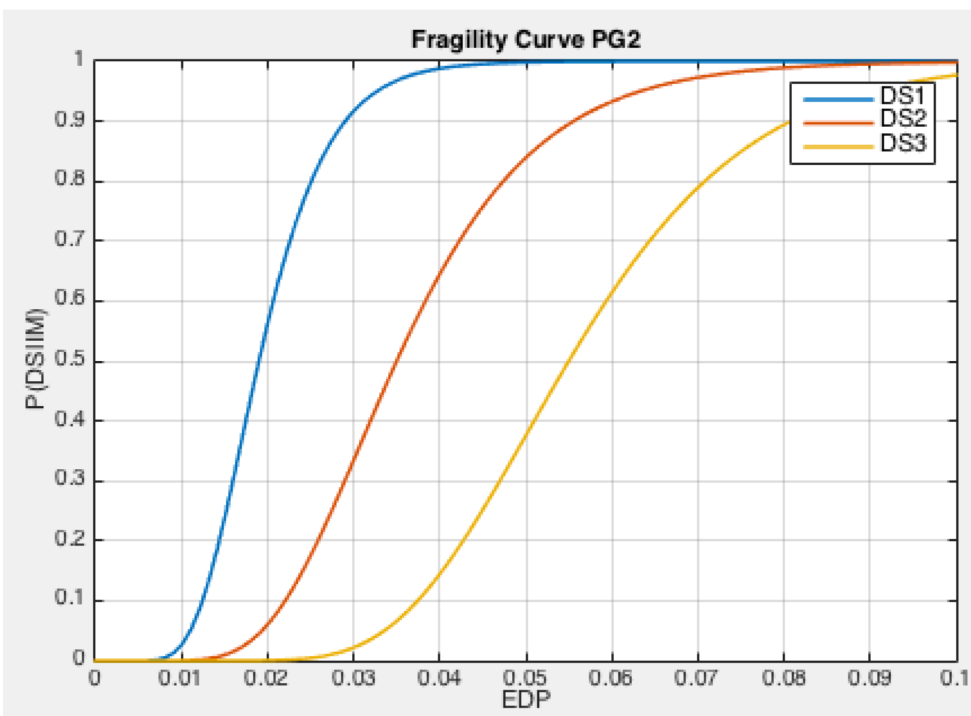


Figure 30: Damage Fragility Curve for Performance Group 2

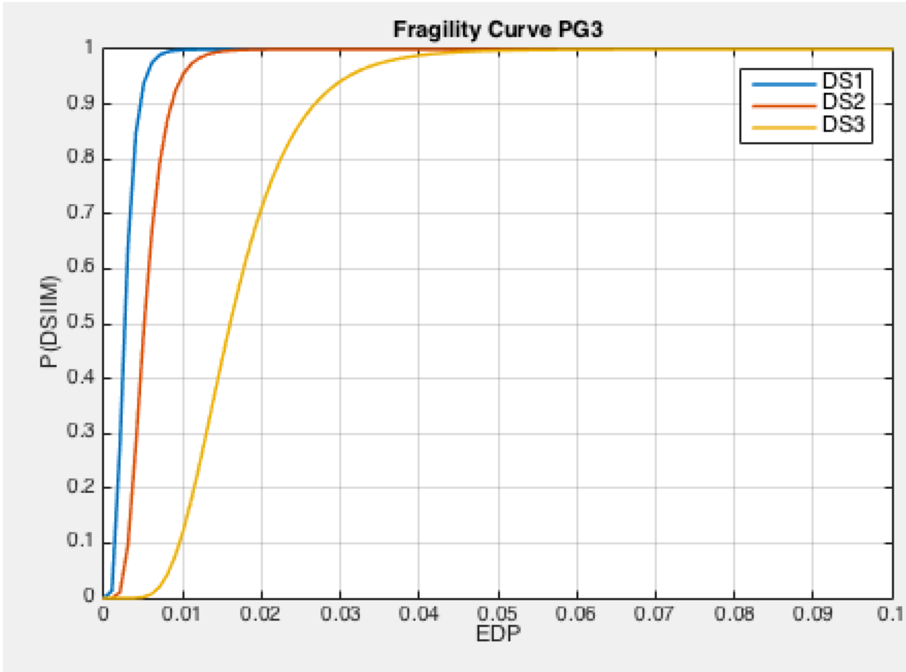


Figure 31: Damage Fragility Curve for Performance Group 3

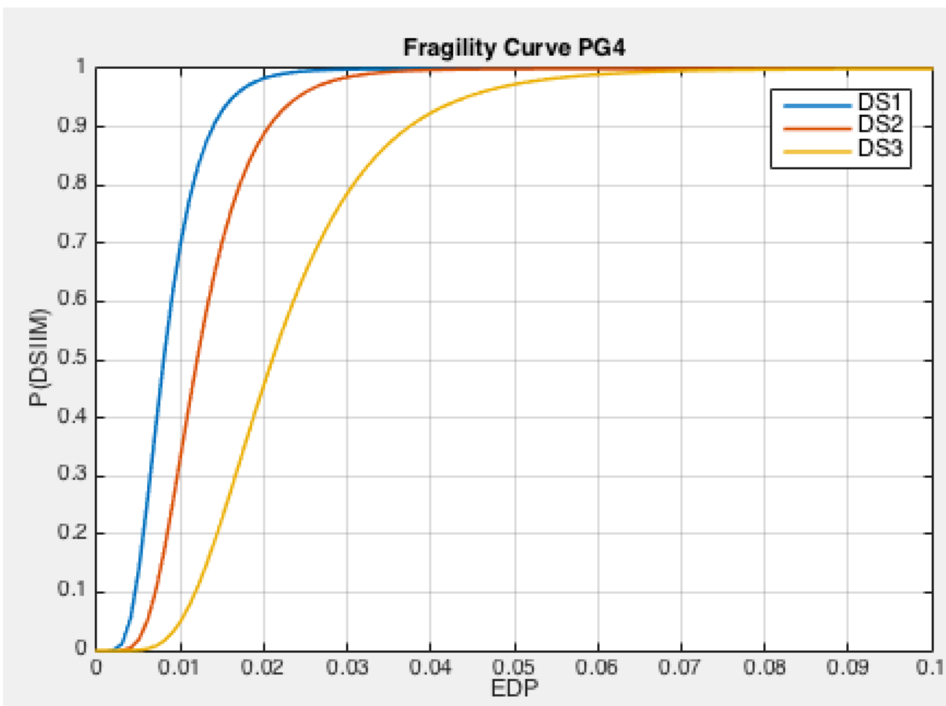


Figure 32: Damage Fragility Curve for Performance Group 4

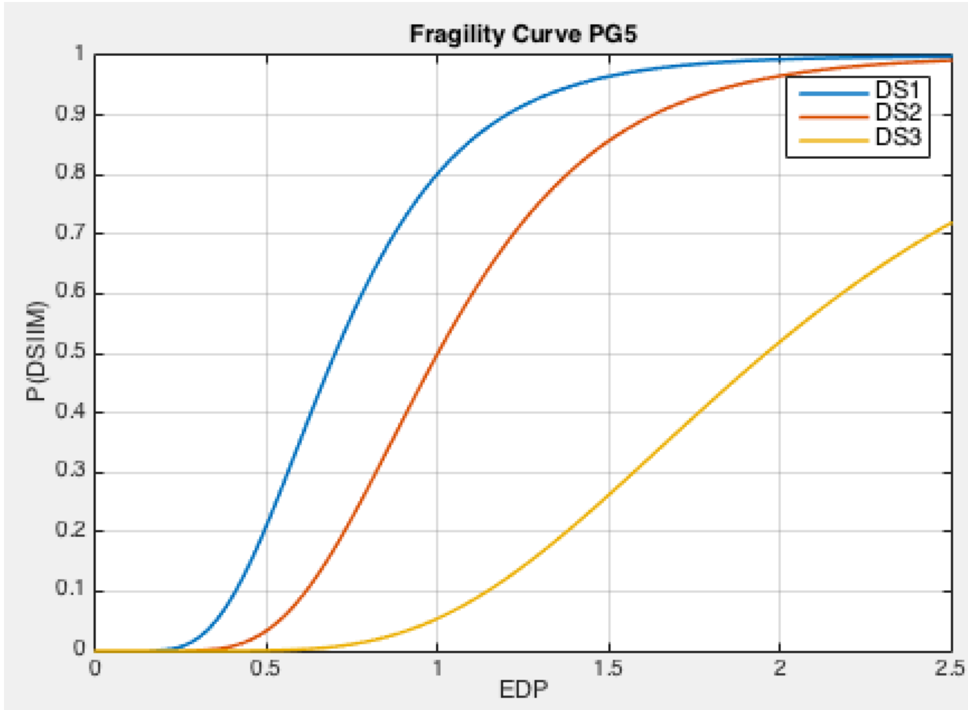


Figure 33: Damage Fragility Curve for Performance Group 5

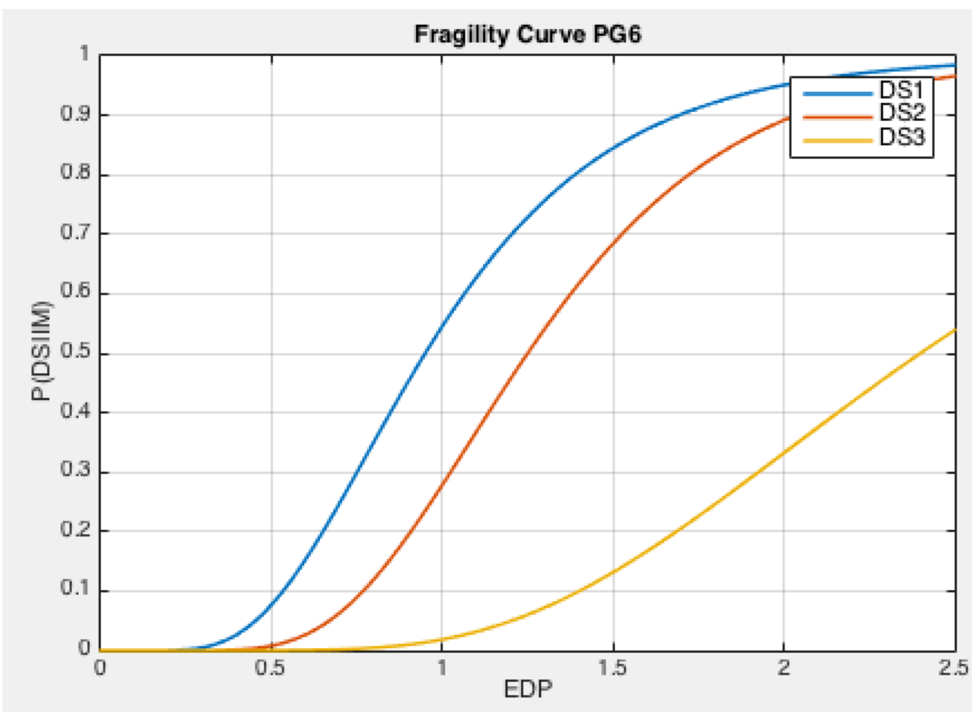


Figure 34: Damage Fragility Curve for Performance Group 6

4.2 Probability of being in each damage state

This section includes plots that show the probability of being in each damage state for each EDP level, for each performance group. Again, as mentioned in the previous section, PG3 and PG4 reach the probability of being in DS3 the fastest compared to the other IDR-based performance groups.

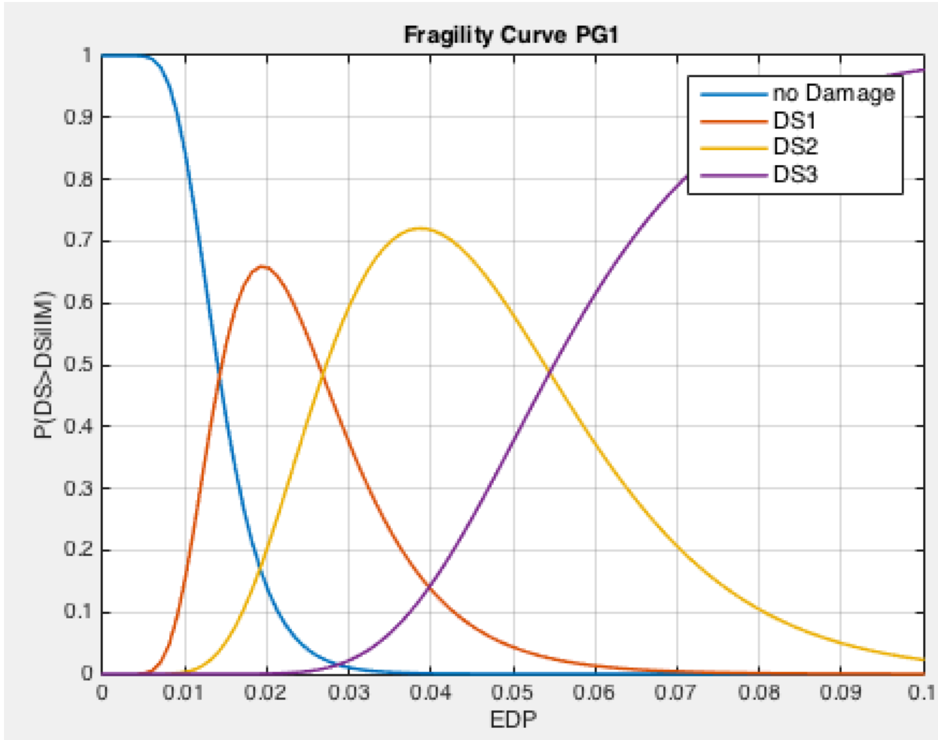


Figure 35: Probability of being in each damage state for performance group 1

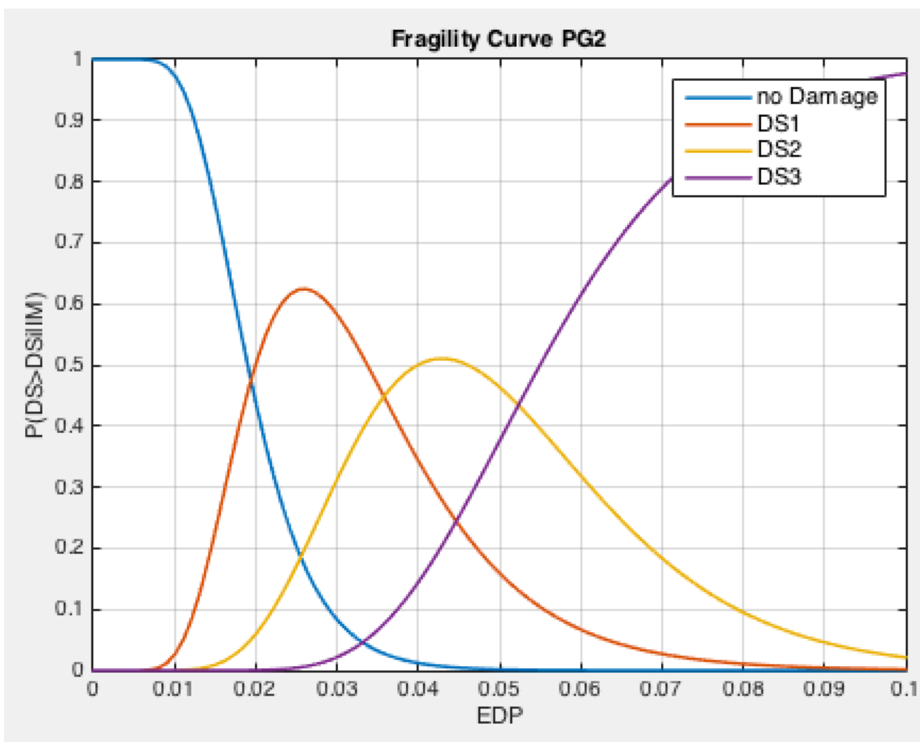


Figure 36: Probability of being in each damage state for performance group 2

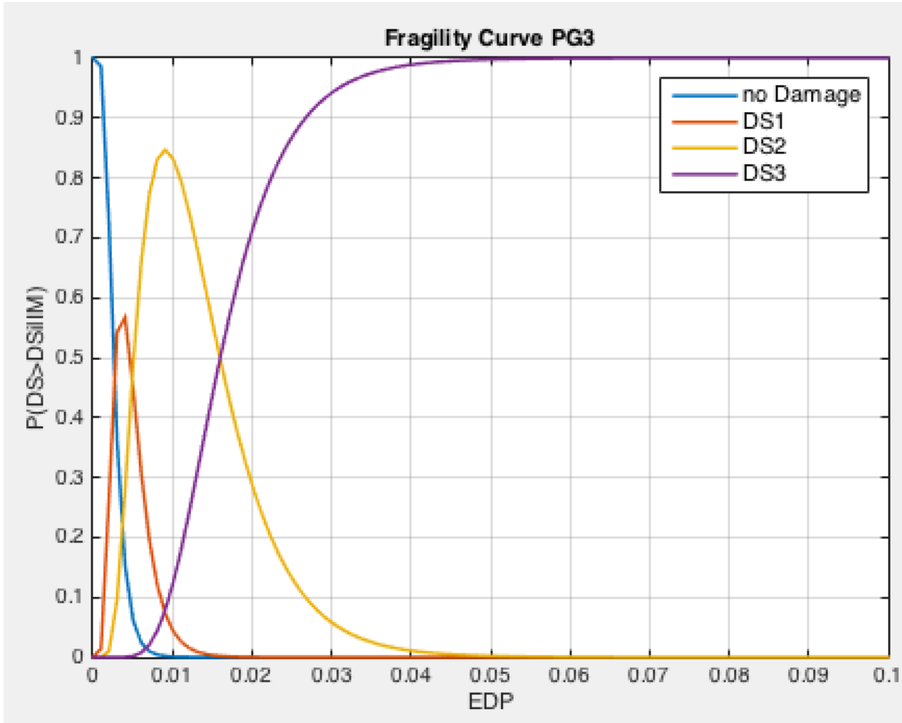


Figure 37: Probability of being in each damage state for performance group 3

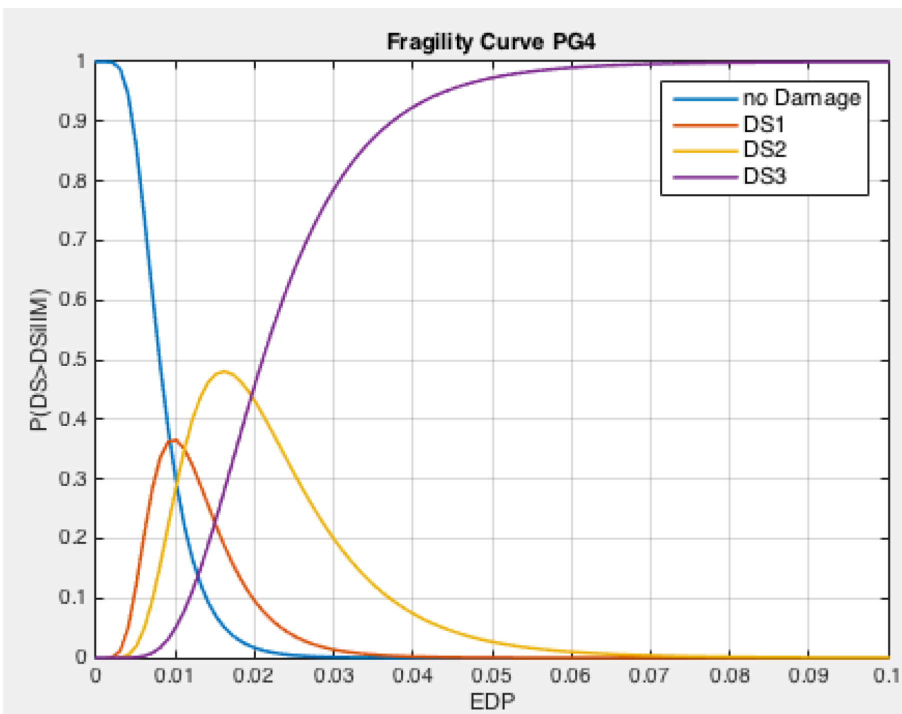


Figure 38: Probability of being in each damage state for performance group 4

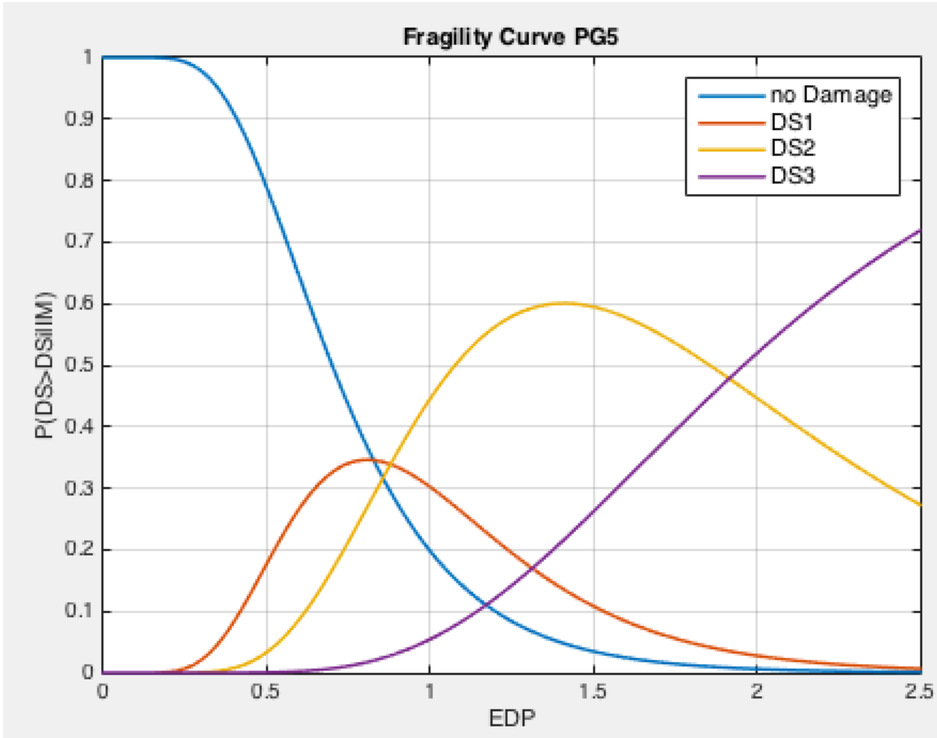


Figure 39: Probability of being in each damage state for performance group 5

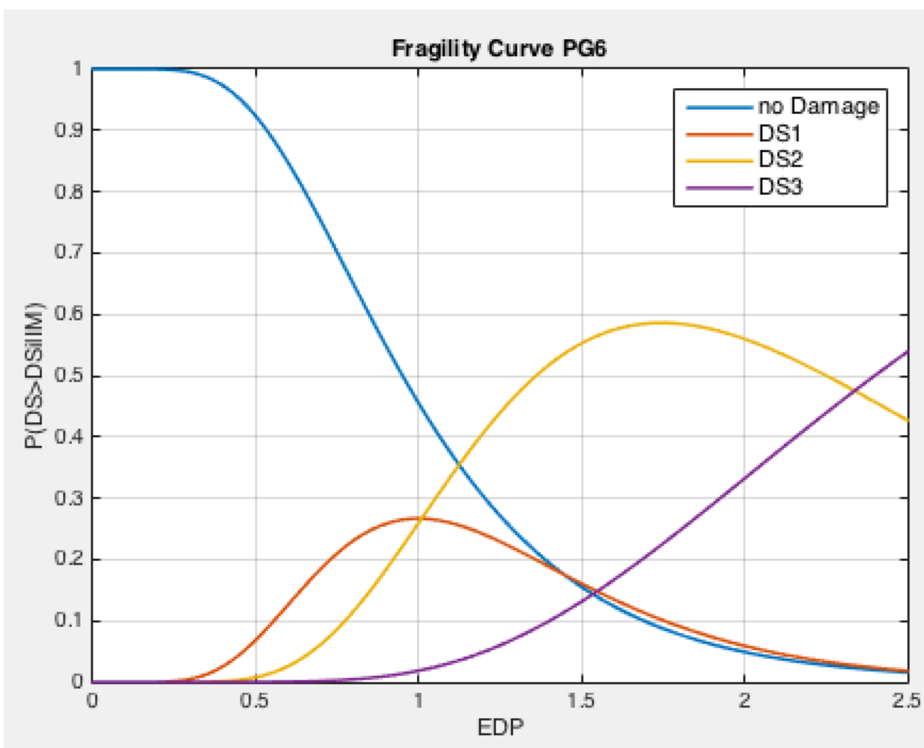


Figure 40: Probability of being in each damage state for performance group 6

4.3 Replacement Cost Distribution per Floor

This section shows the distribution of how each performance group and floor contribute to the total replacement cost. For IDR based PG, Figure 41 shows the sum replacement loss is the highest for floor 1, while PG3 and PG4 contribute the most among all floors. For PFA based PG, Figure 42 shows the sum replacement loss is the highest at the roof. The replacement loss is about the same for all levels for the two PG except for the roof: PG6 contributes more at the roof.

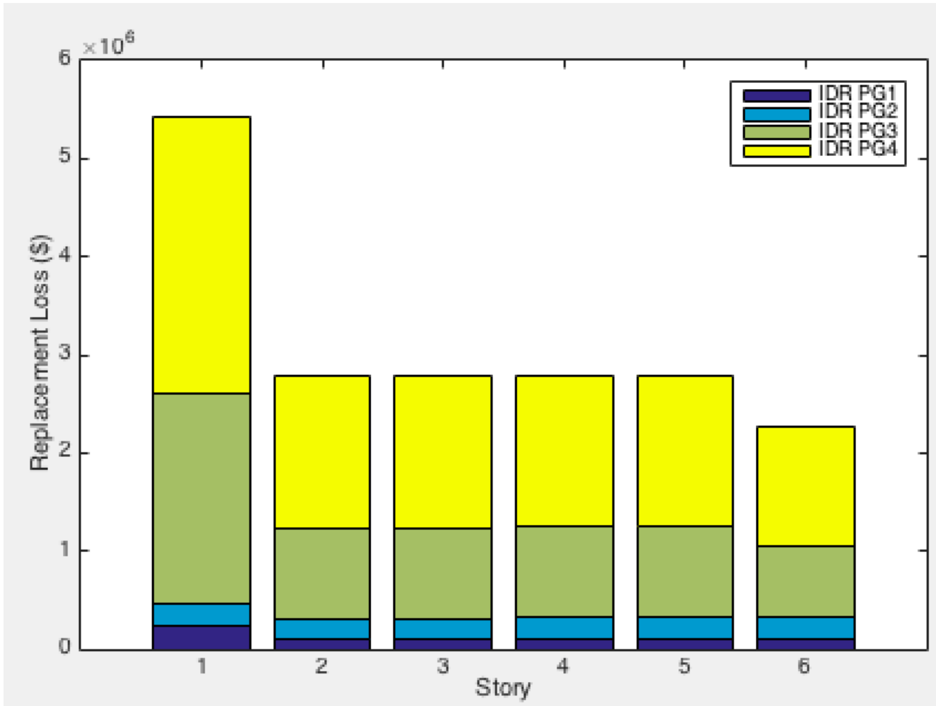


Figure 41: Replacement cost per story per performance group, for performance groups whose damage is based on IDR

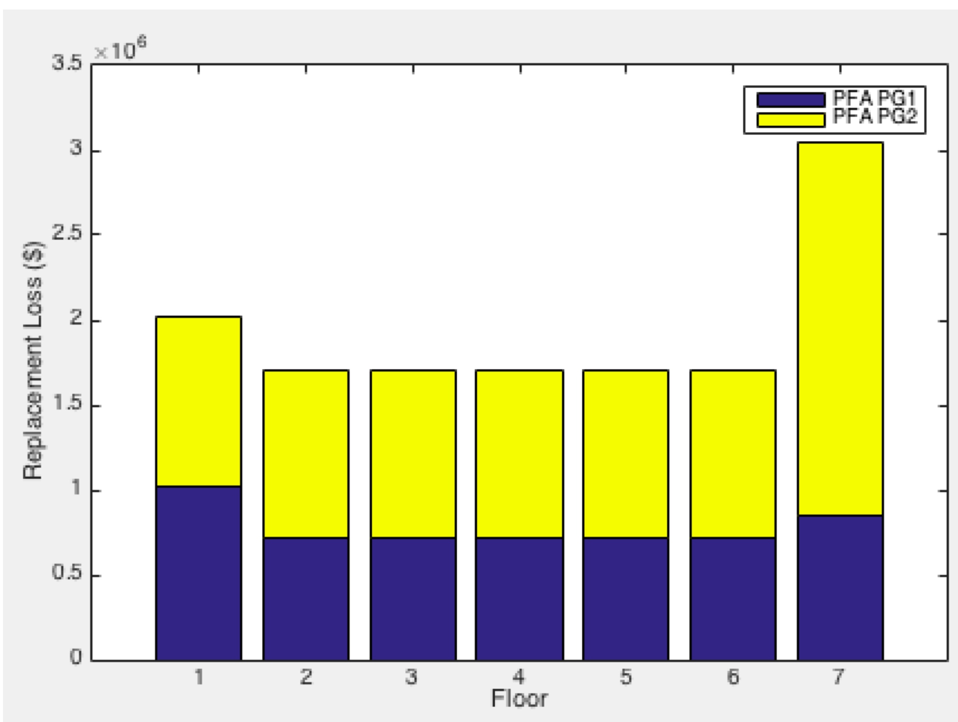


Figure 42: Replacement cost per floor per performance group, for performance groups whose damage is based on PFA

5 Decision Variable

This section discusses loss calculations. The loss file containing expected loss values per floor and per performance group may be loaded on to the GUI using the "Load Loss Function" which becomes available once the fragility calculations are completed. The building loss data should be contained in a .csv file of the format shown in Figure 43. The entries in the .csv must be changed to "Text" format in Excel before being loaded onto the GUI. This is to prevent errors due to dollar signs or commas in the numeric entries.

	A	B	C	D	E	F	G	H
1	TOTAL INVESTMENTS PER PERFORMANCE GROUP AT DIFFERENT STORIES/FLOORS IN US DOLLARS							
2								
3	STORY	PG1	PG2	PG3	PG4	PG5	PG6	TOTAL
4	6	94000	228000	720000	1230000	0	0	2272000
5	5	98000	228000	915000	1547000	0	0	2788000
6	4	98000	228000	915000	1547000	0	0	2788000
7	3	98000	215000	915000	1547000	0	0	2775000
8	2	98000	215000	915000	1547000	0	0	2775000
9	1	245000	215000	2142000	2820000	0	0	5422000
10								18820000
11								
12	FLOOR	PG1	PG2	PG3	PG4	PG5	PG6	TOTAL
13	7	0	0	0	0	845000	2200000	3045000
14	6	0	0	0	0	713000	988000	1701000
15	5	0	0	0	0	713000	988000	1701000
16	4	0	0	0	0	713000	988000	1701000
17	3	0	0	0	0	713000	988000	1701000
18	2	0	0	0	0	713000	988000	1701000
19	1	0	0	0	0	1026000	988000	2014000
20								13564000
21								
22							TOTAL =	32384000
23								
24								
25	REPLACEMENT COST NEW FOR ALL PERFORMANCE GROUPS					1000		
26								
27	EXPECTED VALUE OF THE LOSS IF THE BUILDING IN DEMOLISHED					35000000		
28								
29	EXPECTED VALUE OF THE LOSS IF THE BUILDING COLLAPSES					45000000		
30								

Figure 43: View of sample building data

The "Run Loss" button will calculate annual and expected losses for each IM level from the slope of the seismic hazard curve (the same one used to calculate collapse deaggregation in Section 3.4), for each floor, and for every performance group available in the damage fragility file shown in Figure 27.

Once the calculations have been completed, the annual loss panel in the GUI will update as shown in Figure 44. As shown in the figure, **demolish loss contributes the most to the total annual loss, followed by Non-collapse then collapse case.**

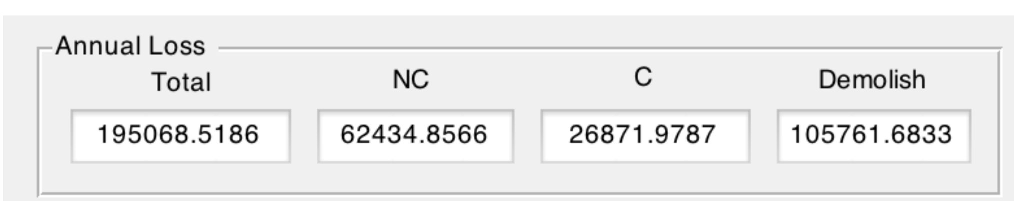


Figure 44: Annual Loss Results

The user now has seven different options to choose from in terms of plotting the loss results, as shown in Figure 45. These are discussed in detail in the following sections.

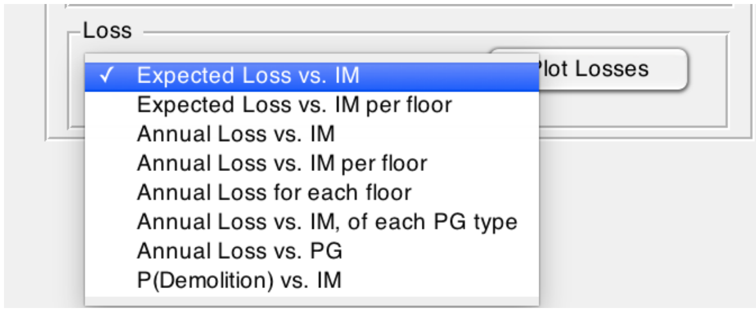


Figure 45: Loss Plot Options

5.1 Expected Loss

The user may now select from two options for viewing expected loss: Expected Loss as a function of IM, and expected loss as a function of IM per floor.

Figure 46 shows the expected loss as a function of IM, summed across all building floors. As shown in the figure, the expected loss given IM for both demolish and non-collapse peaks at around 0.5g then decreases for higher IM level. Expected loss for collapse increases at IM increases.

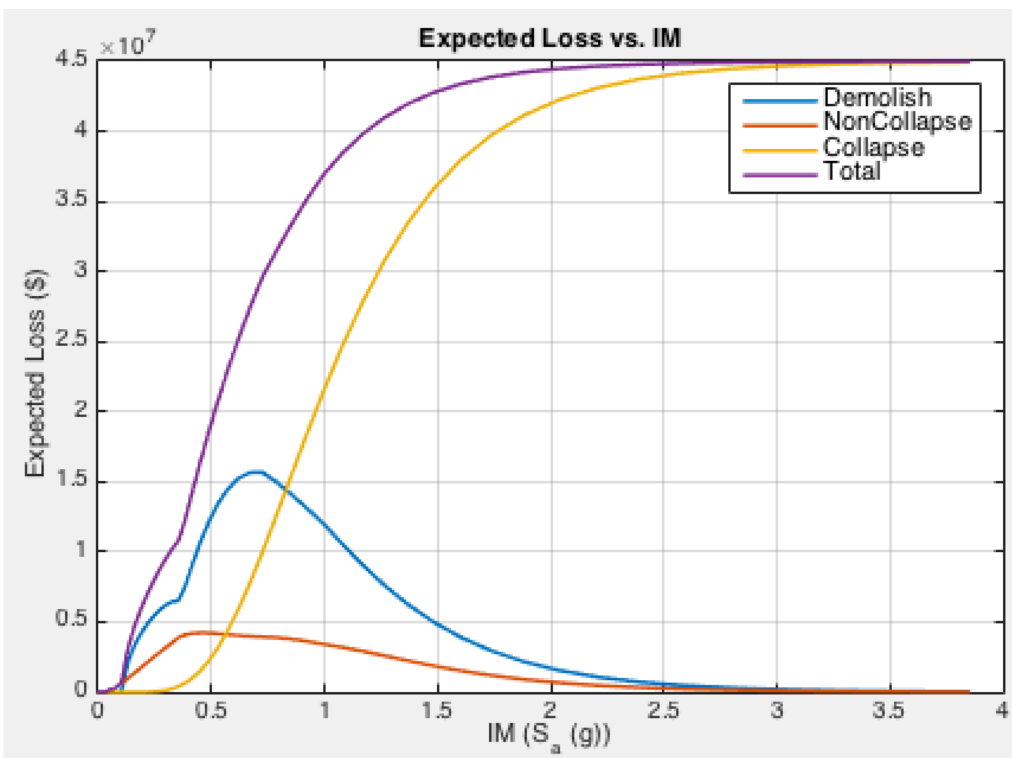


Figure 46: Expected Loss as a function of IM

Figure 47 shows the expected loss per floor, as a function of IM. The values are shown for the non-collapse, non-demolition case, as the expected loss for collapse and demolish cases are for an entire building and not per floor. The expected loss given IM curve is the greatest for level 1 and the least for the roof. This is because most PG groups are IDR based, and the probability of EDP exceedance is the greatest for floor 1 as shown before in Figure 8 of section 3.1.

We also note that the median IM for collapse is approximately 1.0g (see Section 3.4), and that in the above figure, much of the expected loss already accumulates before reaching 1.0g. Thus, if only designing buildings for collapse prevention (which is what the building codes currently dictate), then we are adding extremely fragile and less resilient buildings to the built environment.

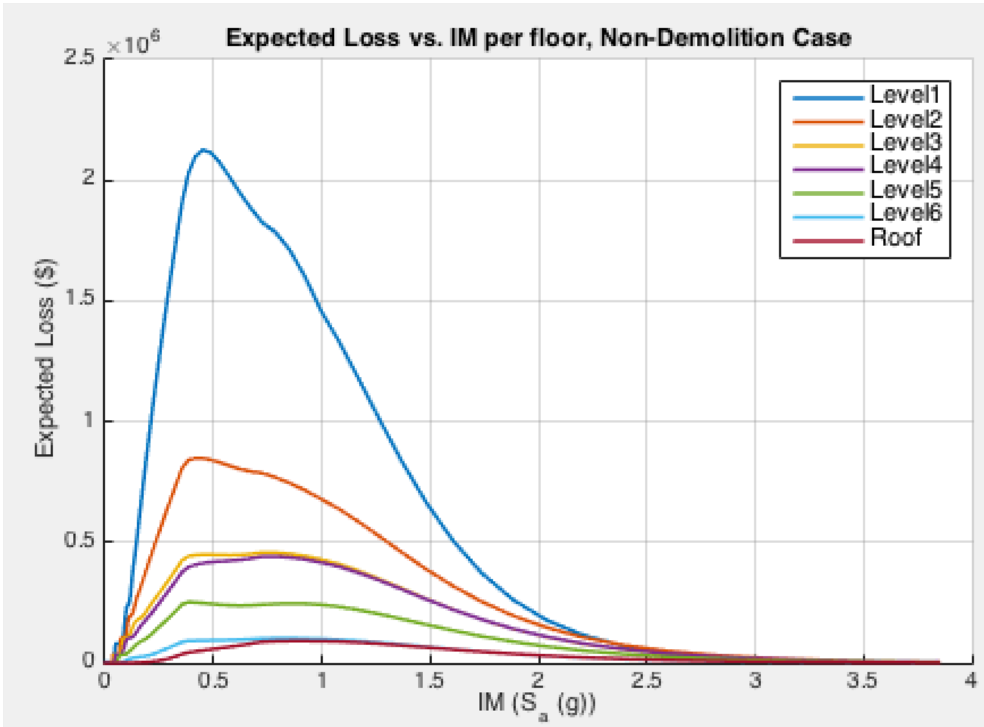


Figure 47: Total Expected Loss, given non-demolition, as a function of IM

5.2 Annual Loss

The following plots show how annual loss is distributed across different IM levels, floors, and performance groups. Annual loss is the loss that factors in the rarity of the different IM levels. Thus, while expected loss may be quite larger for higher IM's, the annual loss distribution should be more concentrated in lower to medium IM's that have a higher chance of occurrence.

The annual loss of the first floor contributes the most of the annual loss for non-collapse, non-demolish case as shown in Figure 50. For all the PG groups, PG3 contributes the most for the annual loss (74.8%), followed by PG4 (23.3%) as shown in Figure 52. This result is to be expected as PG3 and PG4 are nonstructural components that have damage fragility curves reaching 100% of probability of being in DS3 the fastest (see Section 4.1).

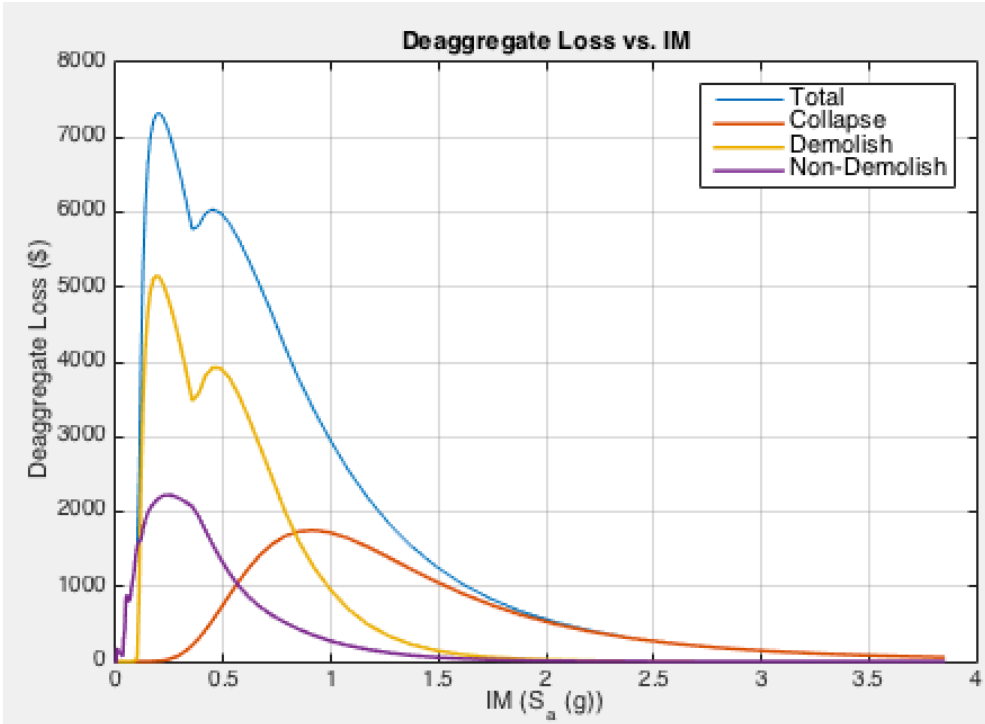


Figure 48: Annual Loss vs. IM

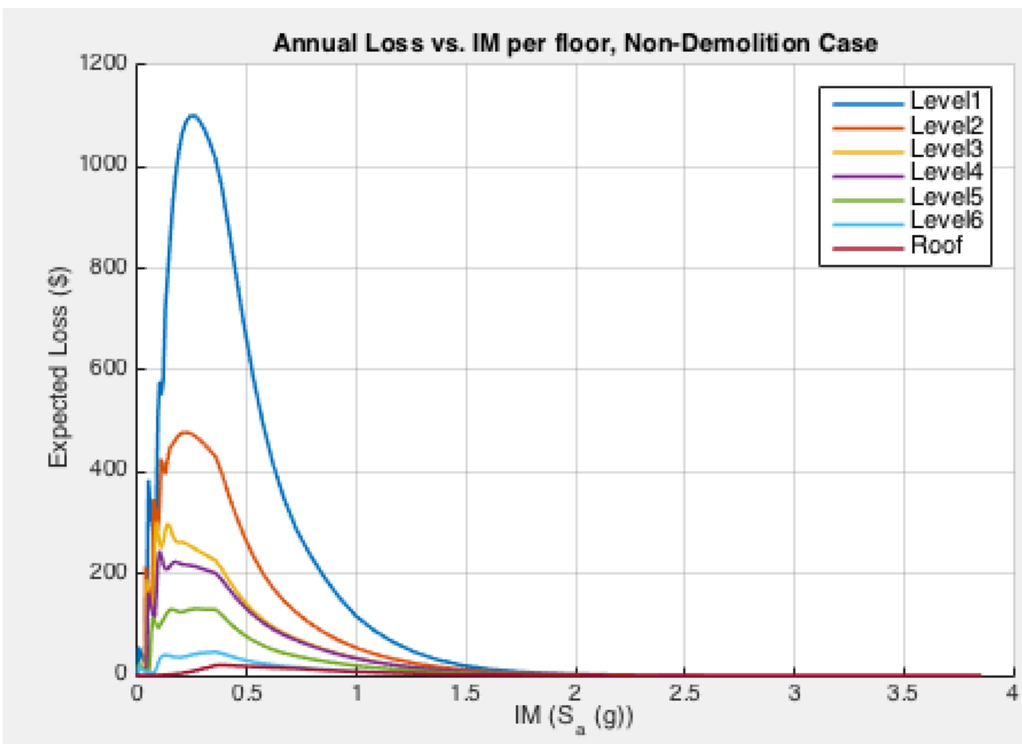


Figure 49: Annual Loss vs. IM, per floor

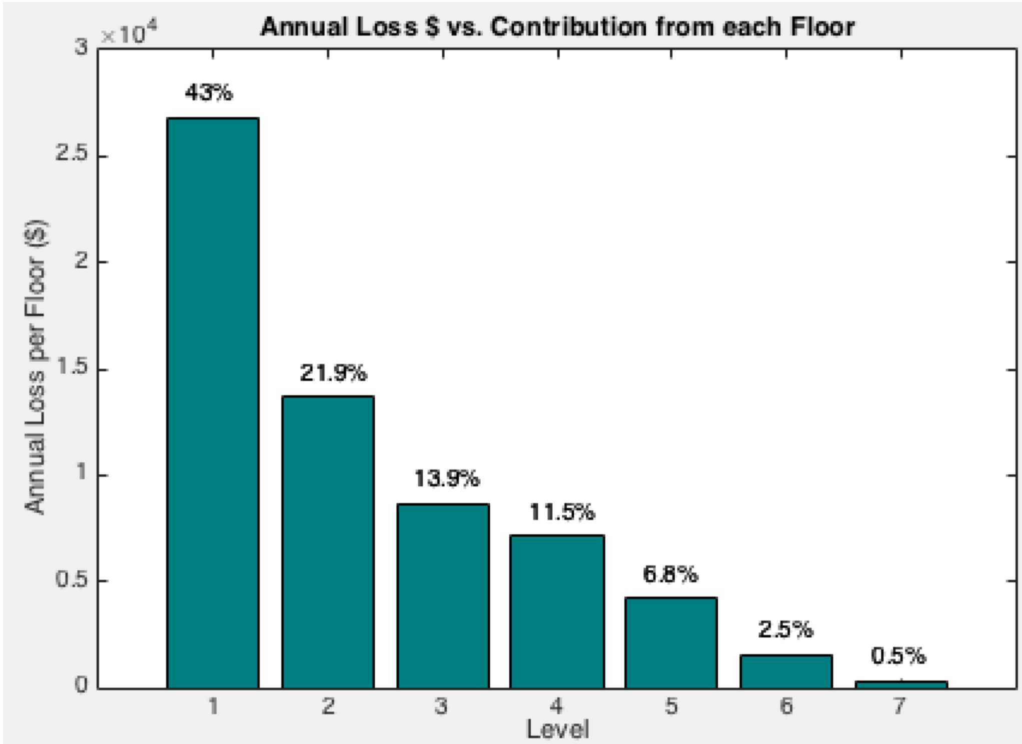


Figure 50: Annual Loss Contribution from each floor. Level 7 indicates the roof

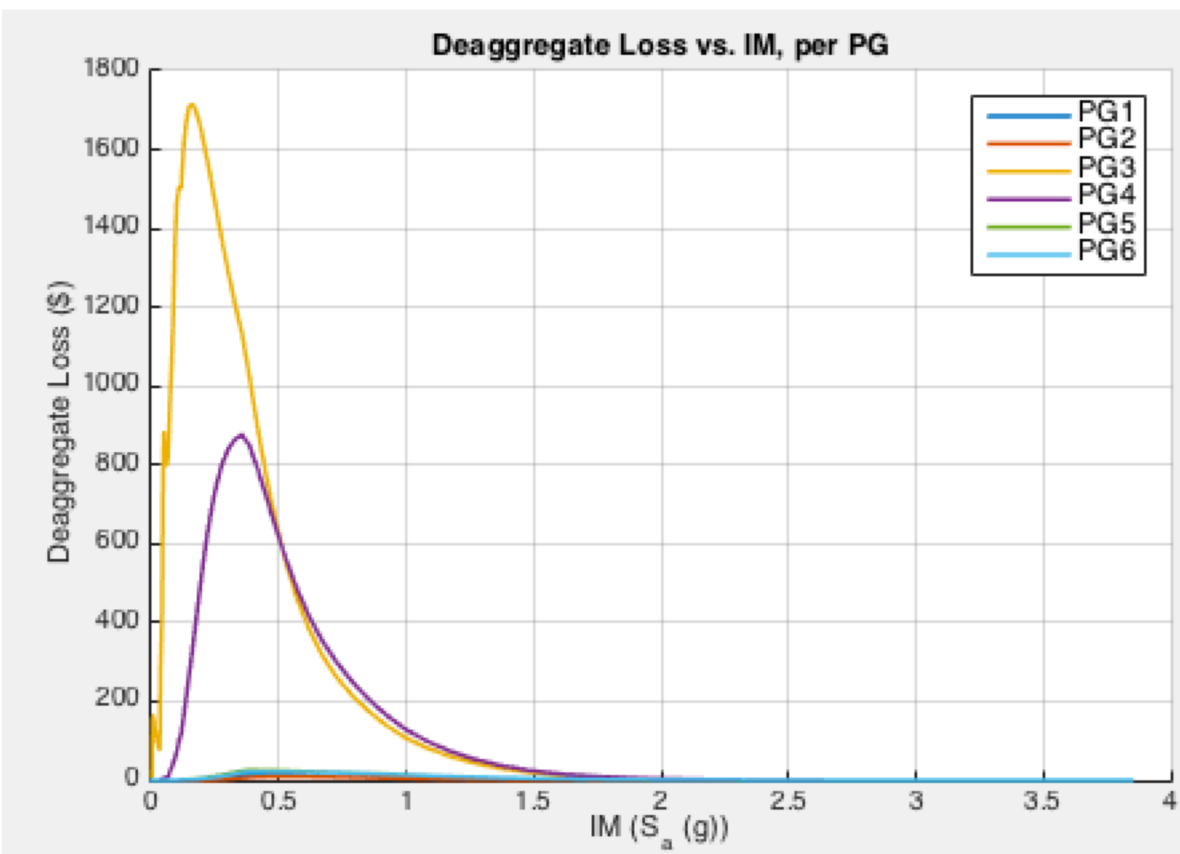


Figure 51: Annual Loss Contribution from each performance group, as a function of IM

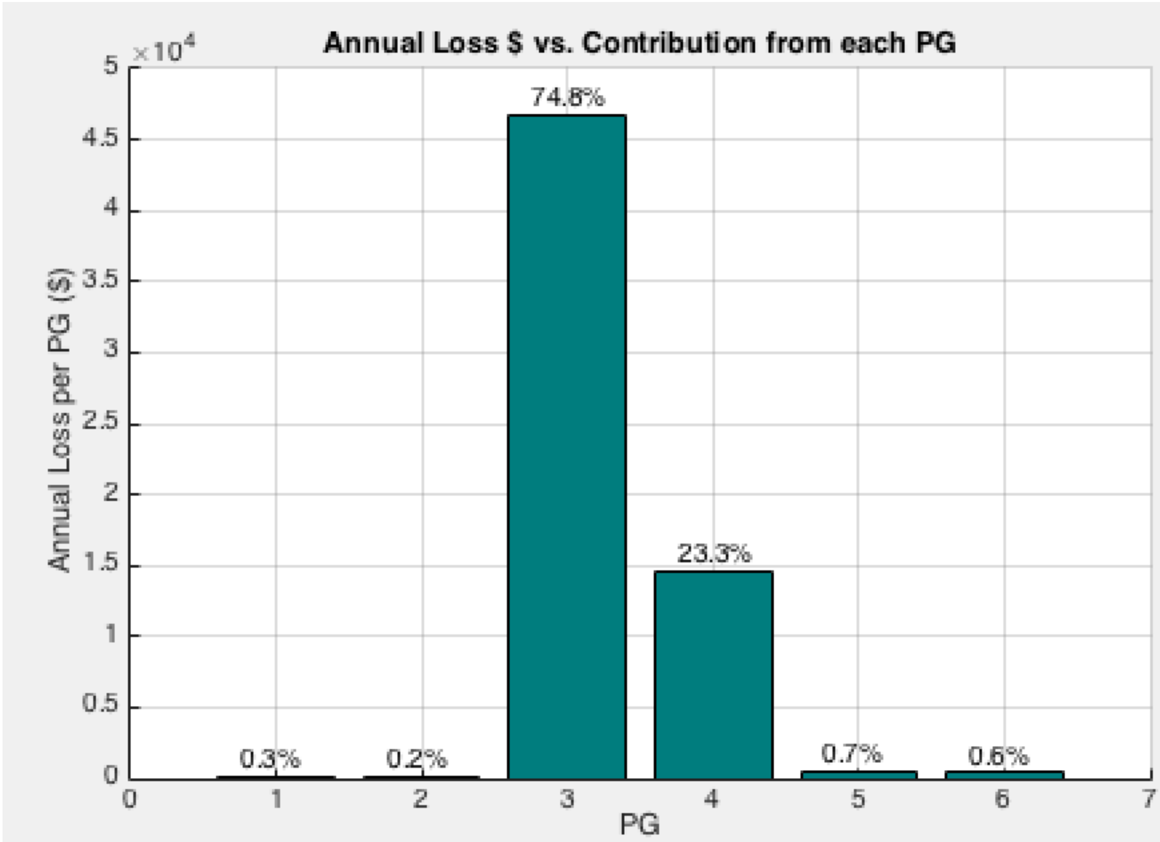


Figure 52: Annual Loss Contribution from Each Performance Group, across all IM values

5.3 Probability of Demolition

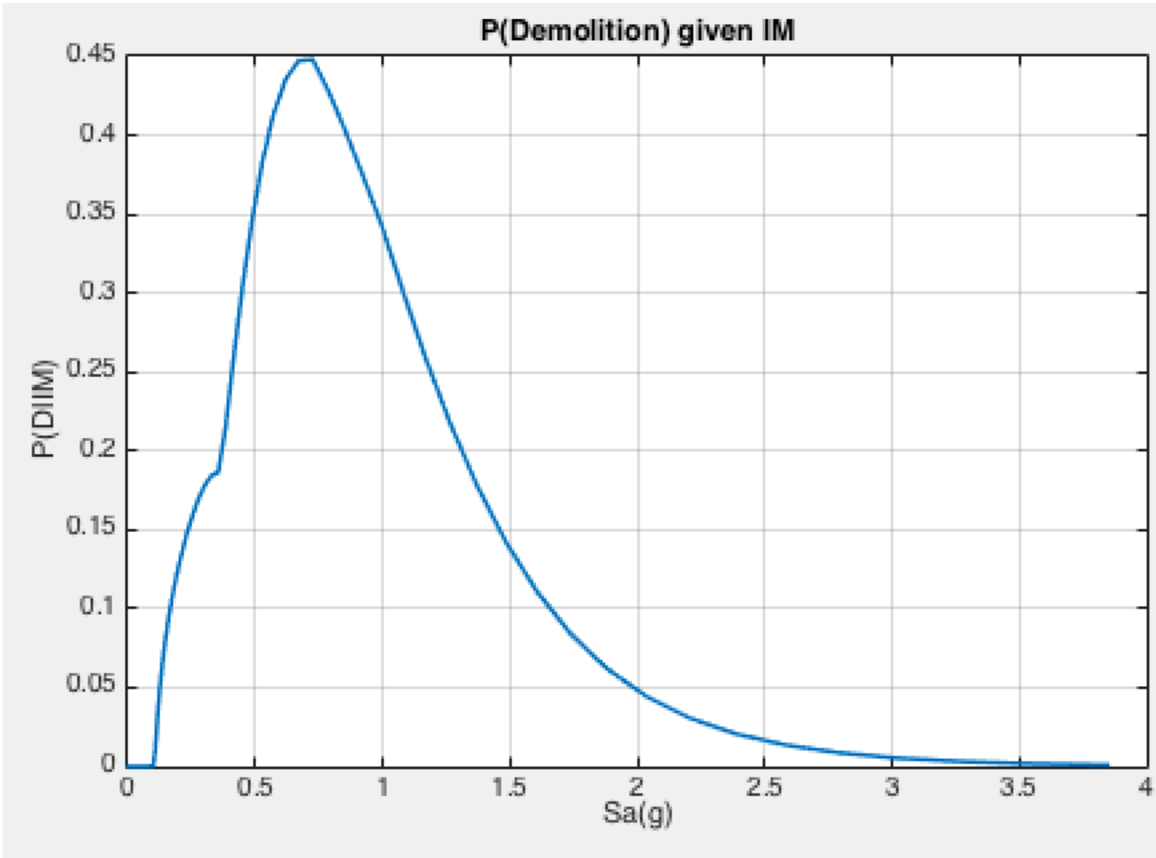


Figure 53: Probability of Demolition as a function of IM

The probability of demolish given IM shown in Figure 53 above already include the probability of non-collapse. Therefore, the probability of demolish starts decreasing at larger ground motion levels because the probability of non-collapse is low at those points.