Eidgenössische Technische Hochschule Zürich
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ETH RISK CENTER

LECTURE NOTES

Fragility functions and losses computation
LAB II

Spring 2018

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1 Problem statement

The goal of this Lab is twofold. First you should perform a fragility analysis for two different structural archetypes. Second you should perform a loss analysis via PEER formula framework. For sake of simplicity we will analyze a single degree of freedom system (SDOF) representative of 2 structural systems. The first structural system is a ductile structure with maximum interstorey drift equal to 3%. The second structural system is a fragile system with maximum interstorey drift equal to the elastic limit state, i.e. 1% interstorey drift.

1.1 Structural properties, ductile system

- Hysteretic model: Bouc Wen.
- Stiffness $k = 2.8\text{E}8[\text{N/m}]$, Post Stiffness $0.01k$.
- Mass $m = 1\text{E}6$ [kg] $\rightarrow T = 0.38[\text{s}]$.
- Damping $c = 2\sqrt{k/m}(0.05)m$
- Yielding point $u_y = 1\%$interstorey drift $\rightarrow u_y = 0.04[\text{m}]$. Assume the hight of the structural system equal to $4[m]$. Collapse point $u_u = 0.12[\text{m}]$.
- Limit states $[DS_1 = 0.8,\ DS_2 = 1,\ DS_3 = 1.5,\ DS_4 = 2,\ DS_C = 3]\%$ interstory drift.

1.2 Structural properties, fragile system

- Linear model up to the collapse point.
- Stiffness $k = 2.8\text{E}8[\text{N/m}]$, Post Stiffness $0.01k$.
- Mass $m = 1\text{E}6$ [kg] $\rightarrow T = 0.38[\text{s}]$.
- Damping $c = 2\sqrt{k/m}(0.05)m$
- Collapse point $u_y = 1\%$interstorey drift $\rightarrow u_y = 0.04[\text{m}]$. Assume the hight of the structural system equal to $4[m]$.
- Limit states $[DS_1 = 0.8,\ DS_C = 1]\%$ interstory drift.

2 Fragility Computation

We ask you to compute the collapse fragility function of the ductile system as follow:

- Given the provided set of ground motions (accelrot_cellarray.mat), perform a classical incremental dynamic analysis (IDA), and compute the computational time and the total number of time history analysis. Determine the fragility for both ductile and fragile system.
- Given the provided set of ground motions, perform a truncated incremental dynamic analysis with max $pga_t = 2.2[g]$, and compute the computational time and the total number of time history analysis.

- Compare the two collapse fragility functions. Figure 1 shows the solution. Comment on the results.
- Compute a multi-stripes analysis by scaling all the ground motions to the following levels $pga_{levels} = [0.10, 0.25, 0.50, 0.75, 1.00, 1.50, 2.00, 2.25]$. Compute the fragility functions for all damage states, Figure 2. Compute the computational time, and observe that you know in advance the total number of time history analysis, which is: total number of earthquakes (31)$\times$ number of pga levels (8) $= 248$. Note that this procedure does NOT take in consideration the correlation between the different stripes (hence it is an approximation). If you are interested to consider the correlation between the stripes you should consider a master thesis.
- Compare the collapse fragility function with the IDA and the truncated IDA. Figure 3 shows the solution. Comment on the results.
- Compute the fragility function via multi-stripe IDA for the fragile system. Observe you do not need to do any new computation.

Problems

- Change the pga truncation level e.g. $pga_t \in [1.2, 1.5, 1.8, 2, 2.5, 3]$. Comment of the sensitivity of the collapse fragility function to the truncation levels. Hint: you do not need to perform the IDA again for the different truncation scheme.
- For the site of Lab 1, perform a disaggregation of the Hazard for different level of intensity (Figure 4). Select the ground motions according the disaggregation analysis. Compute the fragility function via multistripe analysis.
- Consider the epistemic uncertainty of the structural system. In particular compute the fragility for each combination of the following set of structural parameters. $k \in [2, 2.2, 2.4, 2.6, 2.8, 3.0, 3.2]$, $m \in [0.9, 1, 1.1]$, $u_y \in [0.03, 0.04, 0.05]$. Find the envelope of the fragility functions. Note these are epistemic uncertainties.
- Consider different fragility functions, i.e. Beta distribution, logit distribution, Gamma distribution etc. Compute the MLE for each different function and determine the most appropriate one (i.e. the one that gives the highest likelihood).

3 Loss computation

The loss computation is based on the classical PEER formulation as given in Lecture 6 and 7:

$$\lambda(l) = \sum_{d} \int_{im} G(l|ds)P(ds|pga)|d\lambda(pga)|, \quad (1)$$

where l is the loss. To determine the rate of exceedance of the losses, then, we need to define the the loss function, $G(l|ds)$. In this lab, we define 2 loss functions, one for the ductile system and one for the fragile system. The pga rate of exceedance, $\lambda(pga)$, is provided for a site located in Oakland (file: results.cvs), Figure 5.

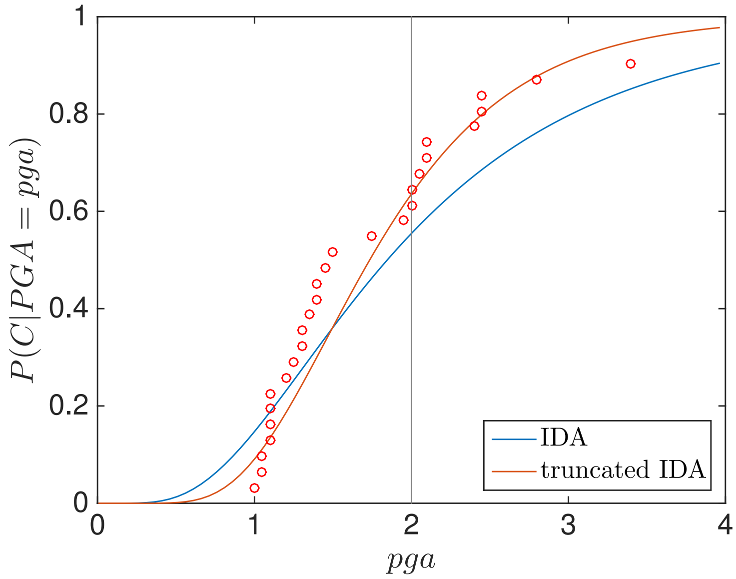

Figure 1: Collapse fragility function computed via IDA vs truncated IDA

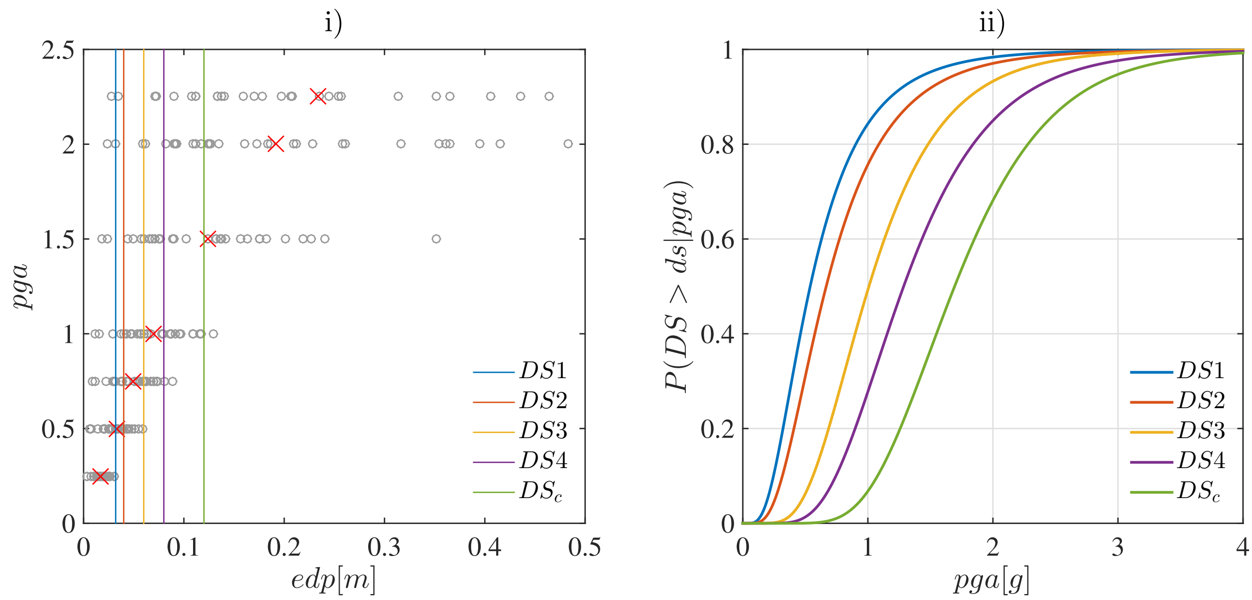

Figure 2: Fragility functions computed via multistripes IDA

3.1 Loss function, ductile system

In this lab, $G(l|ds)$ is assumed to follow a Beta distribution $G(l|ds) \sim \beta(l|ds; \alpha, \beta)$, where the random variable L has finite support [0,1] (i.e. % of direct losses over the building value) and α and β are the parameters distribution. The means and coefficient of variations of the distribution for different damage states, from which α and β can be easily derived, are listed in Table 1. These distributions are given for direct losses over the building value. Figure 8 shows the loss function for the different damage states.

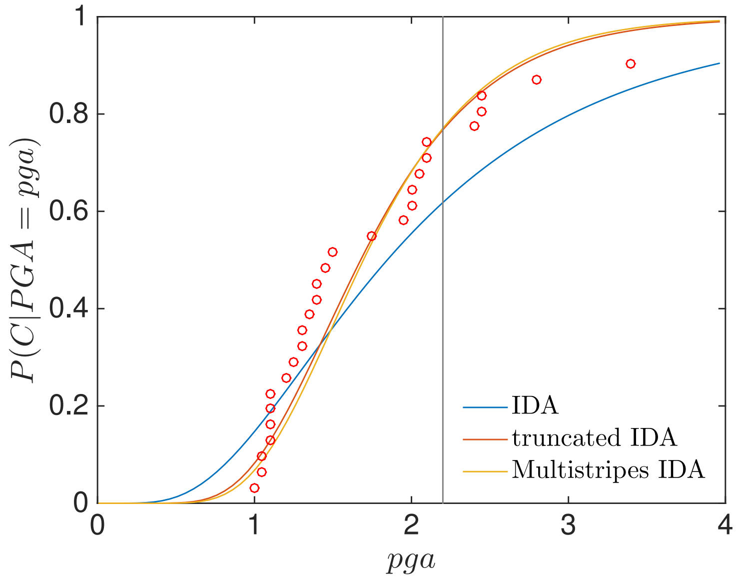

Figure 3: Collapse fragility function computed via IDA, truncated IDA, and multistripes IDA

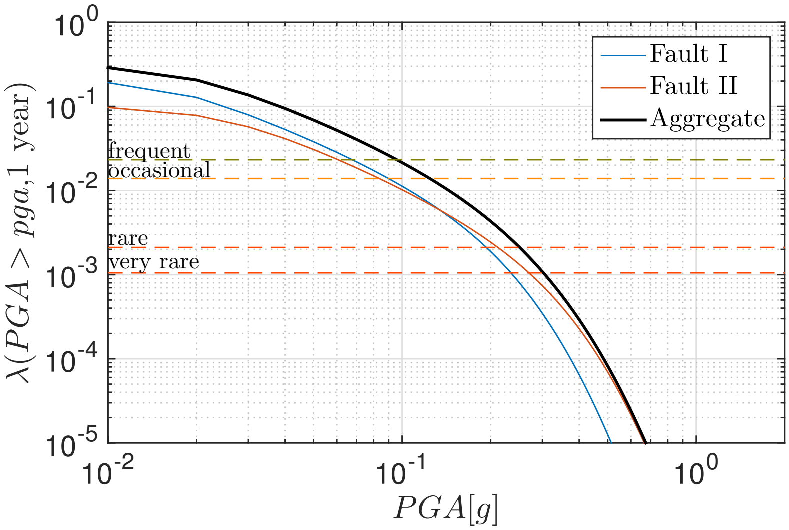

Figure 4: Mean annual rate of occurrence $\lambda(im)$

3.2 Loss function, fragile system

In the case of fragile system there are only two limit state functions. Table 2 reports the parameters and Figure 8 shows the loss functions for the fragile system.

% building value loss	DS_1	DS_2	DS_3	DS_4	DS_c
mean	5%	20%	55%	90%	95%
c.o.v.	0.50	0.50	0.20	0.10	0.05

Table 1: Loss function parameters for ductile system

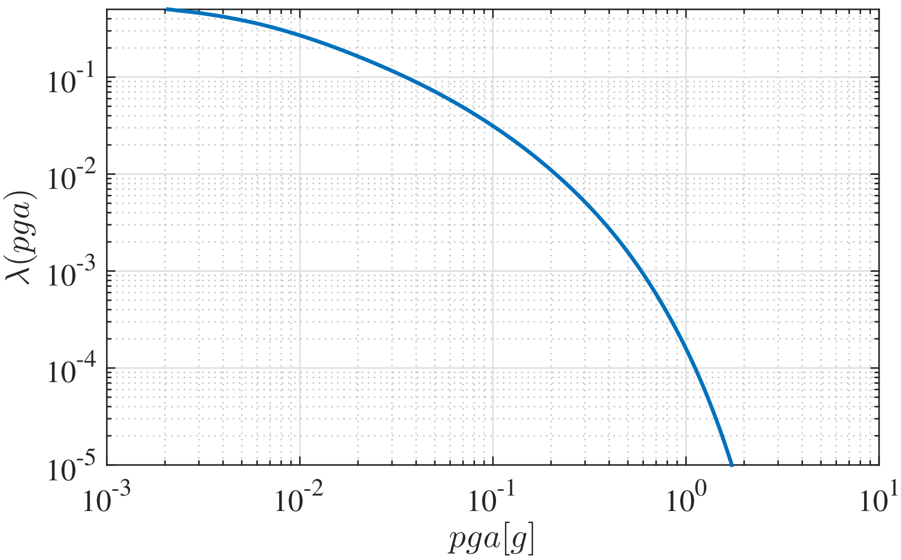

Figure 5: *pga* rate of exceedance

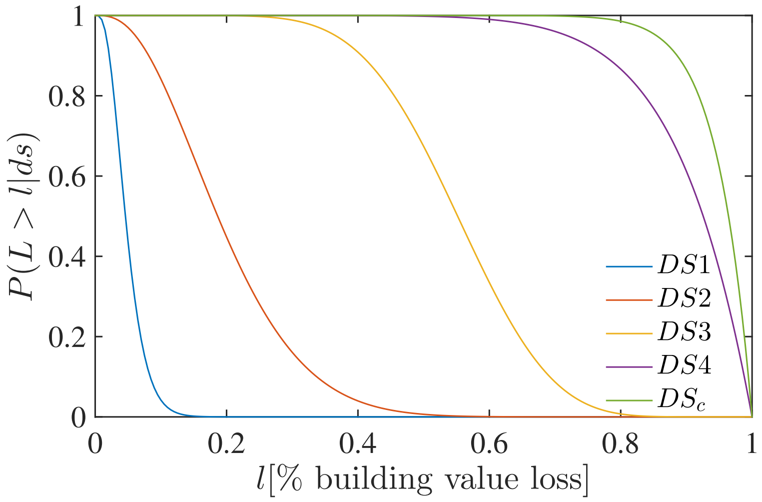

Figure 6: loss functions, ductile system

% building value loss	DS_1	DS_c
mean	5%	95%
c.o.v.	0.50	0.05

Table 2: Loss function parameters for fragile system

- Given the hazard curve, the loss functions, and the fragility functions computed in Section 2, compute rate of losses for the two structural systems, Figure 8 . Comment on the two curves.

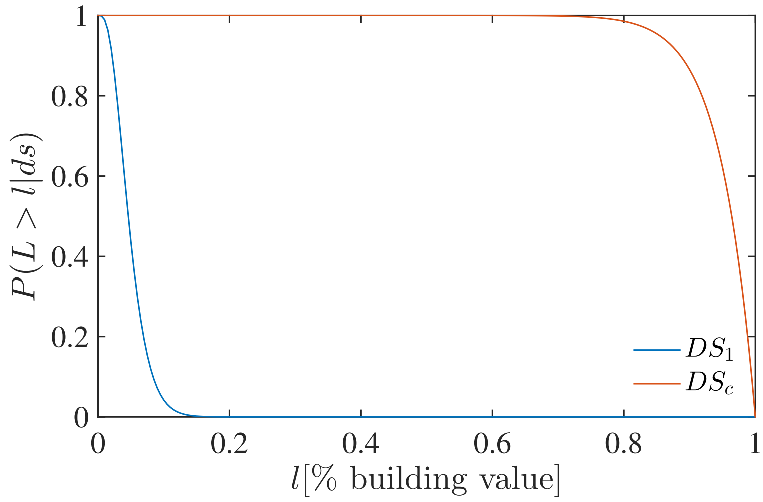

Figure 7: loss functions, fragile system

Problems

- Compute the $P(L > l|t = 50[years])$.
- Compute the loss curves for different level of ductilities, e.g. $DS_c \in [1.2, 1.5, 2, 2.5, 4, 5]\%$. Comment on the results. Assume the the same loss functions as defined in table 1, i.e fix DS_c and derive the other damage states.
- For the aggregate hazard curve of Lab 1 compute the loss curves. Use the fragility functions computed for the Problems of Section 2.
- Compute the $P(L > l|t = 50[years])$ for all the configuration of the fragility function of the last problem in Section 2. PAY ATTENTION to the different nature of uncertainties aleatory vs epistemic.

4 Matlab Routines

Main files

Main_IDA_o_t.m Main file that computes the classical IDA and the truncated IDA. Observe that this file compute the truncated only based on the results of classical IDA. To compute the truncated IDA from scratch (to appreciate the CPU efficiency) rewrite the file.

Main_IDA_stripe.m Main file that computes the multistripes IDA. Observe that this does not take in consideration the correlation between stripes.

Calculate_Curves_lab.m Main file that computes the loss curves. You must complete this script to obtain the loss curves

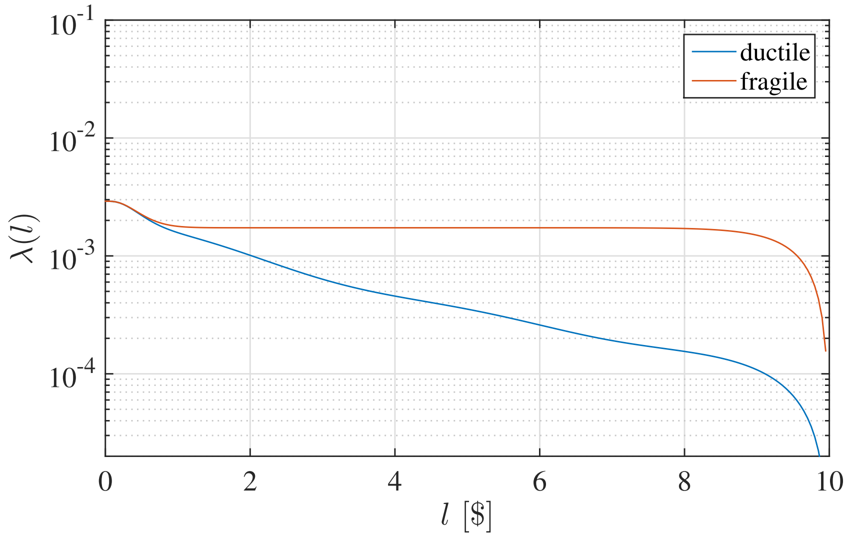

Figure 8: Loss functions

Functions

truncated_ida.m Function which contains the solution of truncated IDA via MLE method, equation (17) of Lecture 8.

fn_mle_pc_m.m The function fits via MLE a lognormal CDF to observed probability of collapse. These calculations are based on equation 27 of Lecture 7.

SDOF_properties_BW.m Script which contains the main material properties of the Bouc-Wen SDOF.

ResponceMDF_Bw.m Function which perform time history analysis of the structural system. You should not touch this function.

BoucwenBN.m Function which compute the material response of the Bouc-Wen model. You should not touch this function.