Scuola Universitaria Superiore IUSS Pavia

ADVANCES IN THE PRACTICAL APPLICATION OF NEXT-GENERATION INTENSITY MEASURES FOR EFFICIENT SEISMIC RISK ASSESSMENT

A Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of Doctor of Philosophy in

EARTHQUAKE ENGINEERING AND ENGINEERING SEISMOLOGY

Obtained in the framework of the Doctoral Programme in

Understanding and Managing Extremes

by

Savvinos Aristeidou

May 2025

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Abstract

This report contains guidelines for formatting a PhD Thesis.

Sommario

Questo rapporto contiene le linee guida per la formattazione di una tesi di dottorato.

Acknowledgements

Acknowledgements can be provided here (though it is not compulsory to include them).

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Nomenclature

List of abbreviations

GGMM	generalised ground motion model.
GMM	ground motion model.
IM	intensity measure.
NGA-West2	next generation attenuation relationships for Western United States.
SDOF	single-degree-of-freedom.

List of symbols

Ds	significant duration.
$FIV3$	filtered incremental velocity.
PGA	peak ground acceleration.
PGV	peak ground velocity.
Sa	5% damped spectral acceleration.
Sa_{avg}	average spectral acceleration.
Sa_{avg3}	average spectral acceleration over the period range $[0.2T,\ 3T]$.

Chapter 1

Guidelines for the PhD thesis

This chapter is extensively based on the following publication:

Aristeidou, S., Tarbali, K., & O'Reilly, G. J. (2023). A Ground Motion Model for Orientation-Independent Inelastic Spectral Displacements from Shallow Crustal Earthquakes. *Earthquake Spectra*, *39*(3), 1601–1624. https://doi.org/10.1177/87552930231180228

1.1 Introduction

Please read carefully the instructions presented herein for the format of a PhD thesis at IUSS Pavia. This document was written to be loosely based on the required format, therefore please read the document for any formatting requirements that are not explicitly stated in the text. Any formatting styles not described herein are either coded in the preamble, or are left to the author's discretion.

1.2 General settings

The page setup options are in the preamble of "`main.tex`" file and described in the following. The margins for A4 size paper should be fixed as: top 6cm, bottom 4.7cm, inside 4cm and outside 3.5cm. The page margins should be mirrored. New chapters should start on odd page numbers and the headers are different on odd and even pages. The header and footer should be set at 4.8cm and 1.5cm from edge, respectively. It must be ensured that first page of each chapter is located on the right-hand side of the double-sided document.

1.3 Formatting and styling

The formatting settings are already implemented in the LaTex files. Nevertheless, they are also summarised along the text herein. All the styles are set in the preamble.

1.3.1 The body text

The language of the main text should be set to English (United Kingdom). Abbreviations are allowed but should be spelt out in full when first used in the abstract, introduction, and conclusions chapters. Integers from one to ten should be written out in words. Foreign language phrases should be italicised (e.g., Latin, French).

1.3.2 Header and page numbering

The header should vary for the first, odd and even pages: there should be no header on the first page of each section/chapter, on even pages the title of the chapter should be inserted (it is automatically reported if added in the first page of the chapter), whilst the name of the author should be placed on the header of odd pages. The text size of headers and page numbers is "\small". Page numbers should be flush outside on odd pages and flush inside on even pages. The preliminary pages of the thesis from the Abstract to the last page of the Nomenclature should be numbered using Roman numerals (i.e. i, ii, iii). The page numbers should restart using Arabic numbers (i.e. 1, 2, 3) on the first page of Chapter 1 and should continue until the last page of the report/thesis.

It is worth mentioning that the user can modify the font style of the document and the template will be completely updated.

Figure 1.1. Example figure

1.3.3 Equations, figures and tables

Equations should be centred within the text width, whilst equation numbers should be placed in parentheses and set flush with the right margin, as illustrated in Equations 1.1 and 1.2.

$$\mu_{\ln \mathrm{IM_i} | \ln \mathrm{IM}^*, \mathrm{rup}} = \mu_{\ln \mathrm{IM_i} | \mathrm{rup}} + \sigma_{\ln \mathrm{IM_i} | \mathrm{rup}} \cdot \rho_{\ln \mathrm{IM}_i, \ln \mathrm{IM}^*} \cdot \epsilon_{\ln \mathrm{IM}^*} \tag{1.1}$$

$$\sigma_{\ln \mathrm{IM_i} | \ln \mathrm{IM}^*, \mathrm{rup}} = \sigma_{\ln \mathrm{IM_i} | \mathrm{rup}} \cdot \sqrt{1 - \rho^2_{\ln \mathrm{IM_i}, \ln \mathrm{IM}^*}} \tag{1.2}$$

In equations, the text, variables and functions should be in *Italic*, whilst numbers, functions and subscripts should not. The sequence of braces, brackets, and parentheses in equations should generally be {[()]}, with due consideration given to the specific meanings associated with different types of brackets.

Figures should be included in the report as illustrated in Figure 1.1; there should be 3pt space before and 6pt space after each figure. A caption should be inserted using the pre-defined format in the preamble. The captions of figures should be centred.

Tables should have the format shown in Table 1.1. The captions of tables should be centre-aligned and justified (as in Table 1.1). Titles of the cells should be in bold font, and for the contents a smaller font size may be used (e.g., "\small").

1.3.4 References

All references should be cited in the text by name and year and may take one of the following forms: "...as shown by Tarbali et al. (2019), the..." or "...has often been demonstrated (Dávalos & Miranda, 2019, 2020; Aristeidou & O'Reilly, 2024) that..." The reference list should be placed at the end of the thesis, but before the appendices (if any), and

Table 1.1. Modal analysis results of the case study bridge.

		Modal participation mass ratios [%]					
Mode	**Period [sec]**	$\boldsymbol{U_x}$	$\boldsymbol{U_y}$	$\boldsymbol{U_z}$	$\boldsymbol{\Phi_x}$	$\boldsymbol{\Phi_y}$	$\boldsymbol{\Phi_z}$
1	0.604	48.5	0	0	0	31.1	0
2	0.363	50.5	0	0	0	34.6	0
3	0.352	0	88.3	0	0.5	0	0
4	0.336	0	0	75.4	0	0	0

must be in alphabetical order by first authors' surnames and presented in the style shown in the examples in the reference section of these guidelines.

1.3.5 Appendices

Any appendices included in the document should be numbered alphabetically and placed at the end of the thesis after the references (see example at the end of this document).

Chapter 2

Example second chapter

This chapter is extensively based on the following publication:

Aristeidou, S., Shahnazaryan, D., & O'Reilly, G. J. (2025). Correlation Models for Next-Generation Amplitude and Cumulative Intensity Measures using Artificial Neural Networks. *Earthquake Spectra*, *41*(1), 851–875. https://doi.org/10.1177/87552930241270563

2.1 Introduction

Example figures are shown in Figures 2.1 and 2.2, inserted from a pdf file and svg file, respectively.

2.2 Discussion and conclusions

This study presented the empirical correlations between assorted intensity measures (IMs) of various types, namely peak ground acceleration, PGA, peak ground velocity, PGV, spectral acceleration, Sa, significant duration, Ds, average spectral acceleration, Sa_{avg}, and $FIV3$. The residuals, which are used for the calculation of correlations, were obtained from a previously developed generalised ground motion model (GGMM) and the same filtered ground motion database. This is believed to produce more consistent correlation coefficients since the same database subset is used for the development of the ground motion model (GMM) and the calculation of empirical correlation coefficients.

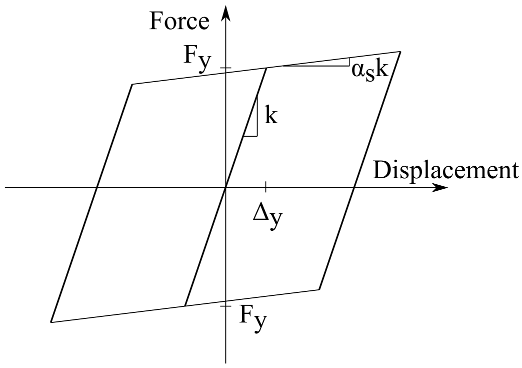

Figure 2.1. Hysteretic behaviour of the bilinear single-degree-of-freedom (SDOF) model (inserted from a pdf file)

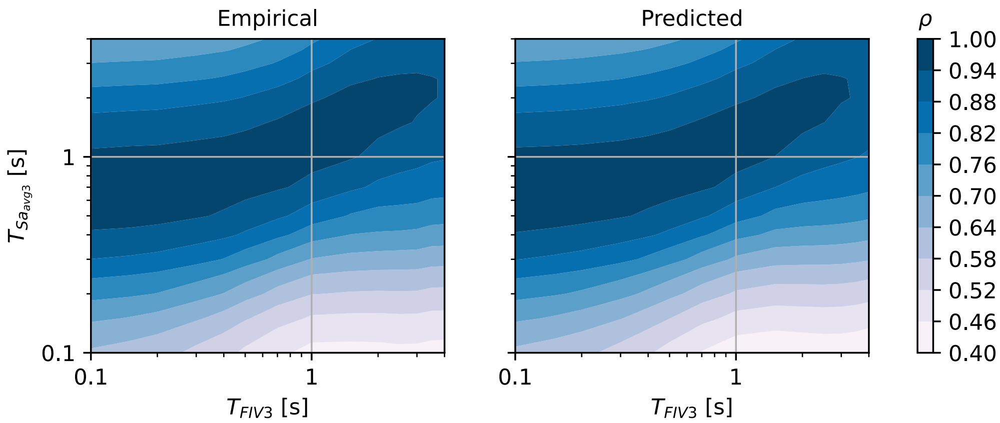

Figure 2.2. Empirical and corresponding predicted correlation coefficients between Sa_{avg3} and filtered incremental velocity, $FIV3$ (inserted from an svg file)

References

Aristeidou, S., & O'Reilly, G. J. (2024). Exploring the Use of Orientation-Independent Inelastic Spectral Displacements in the Seismic Assessment of Bridges. *Journal of Earthquake Engineering*, *28*(12), 3515–3538. https://doi.org/10.1080/13632469.2024.2343067

Aristeidou, S., Shahnazaryan, D., & O'Reilly, G. J. (2025). Correlation Models for Next-Generation Amplitude and Cumulative Intensity Measures using Artificial Neural Networks. *Earthquake Spectra*, *41*(1), 851–875. https://doi.org/10.1177/87552930241270563

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Dávalos, H., & Miranda, E. (2019). Filtered incremental velocity: A novel approach in intensity measures for seismic collapse estimation. *Earthquake Engineering & Structural Dynamics*, *48*(12), 1384–1405. https://doi.org/10.1002/eqe.3205

Dávalos, H., & Miranda, E. (2020). Evaluation of FIV3 as an Intensity Measure for Collapse Estimation of Moment-Resisting Frame Buildings. *Journal of Structural Engineering*, *146*(10), 1–14. https://doi.org/10.1061/(asce)st.1943-541x.0002781

Tarbali, K., Bradley, B. A., & Baker, J. W. (2019). Ground motion selection in the near-fault region considering directivity-induced pulse effects. *Earthquake Spectra*, *35*(2), 759–786. https://doi.org/10.1193/102517EQS223M

Appendix A. Influence of database subset selection on correlation coefficients

This appendix briefly examines what is the main cause of difference between the cross-correlation coefficients proposed here and the ones available in the literature. With that, more general conclusions can be outlined on the importance of different decisions when developing correlation models.

In Figure A.3 four different next generation attenuation relationships for Western United States (NGA-West2) GMMs were used with the same filtering criteria. The filtering criteria are the ones actually used in this study. It can be clearly seen that the correlations obtained from the different GMMs give very similar results. Therefore, we can safely say that the correlation results are not biased by the use of a single GMM and that the ASO24 model is also in line with the others.

The same records and same GMM as BB17 was used to calculate the correlations and compared with the BB17 model itself in Figure A.4. The BB17 model used the NGA-West2 database and is very close to BJ08 model. The results, as expected, are very close. The figures in this appendix constitute strong evidence that the difference comes from the filtering (i.e., subset selection) of the database and not from the background GMM adopted.

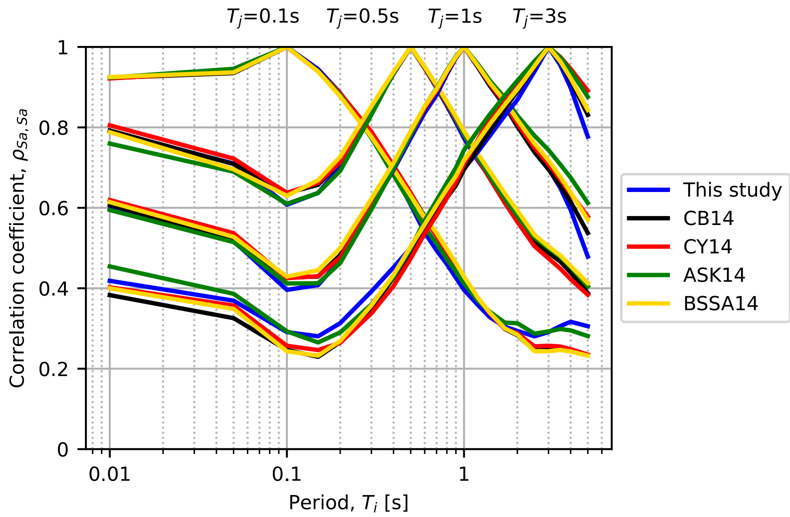

Figure A.3. Comparison of correlation coefficients derived from utilising each of the four NGA-West2 GMMs and the one employed for this study

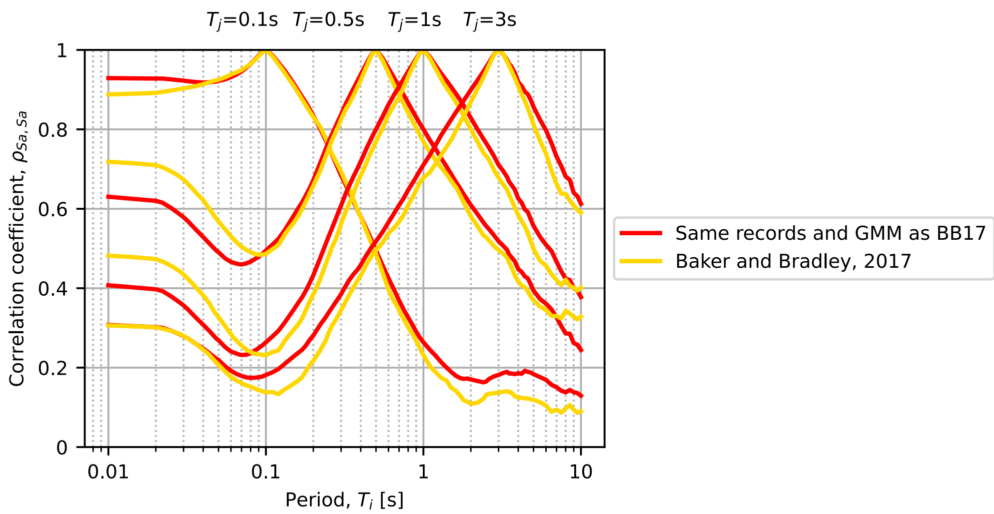

Figure A.4. Correlations proposed by BB17, and the ones calculated here with the same GMM (i.e., CY14) and the same ground motion records