# SEISMIC VULNERABILITY ASSESSMENT OF MASONRY INFILLED REINFORCED CONCRETE SCHOOL BUILDING FRAMES IN SRI LANKA

Mathavanayakam Sathurshan

(218112V)

Degree of Master of Science

Department of Civil Engineering

University of Moratuwa
Sri Lanka

November 2022

# SEISMIC VULNERABILITY ASSESSMENT OF MASONRY INFILLED REINFORCED CONCRETE SCHOOL BUILDING FRAMES IN SRI LANKA

Mathavanayakam Sathurshan

(218112V)

Dissertation submitted in partial fulfillment of the requirement for the degree of Master of Science in Structural Engineering

Department of Civil Engineering

University of Moratuwa
Sri Lanka

November 2022

## DECLARATION

"I declare that this my own work and this dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other university or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by other person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my dissertation, in whole or in part in print, electronic r other medium. I retain the right to use this content in whole or part in future works."

Signature:…………………………… Date:………./……./….. 2023 03 18

The above candidate has carried out this research for the Master Dissertation under my supervision.

Name of the Supervisor: Prof. H. M. Y. C. Mallikarachchi

Signature of the supervisor: ……………………. Date:…19…/…03…/…2023

Name of the Supervisor: Dr. J. A. Thamboo

Signature of the supervisor: ……………………. Date:..19…../03…./2023

Name of the supervisor: Prof. K. K. Wijesundara

Signature of the supervisor UOM Verified Signature te:………./……./…...

# ACKNOWLEDGEMENT

I would like express my profound gratitude to **Prof. H. M. Y. C. Mallikarachchi** of the University of Moratuwa for accepting me as an MSc student and for his unfailing support throughout the wonderful trip. Also, the technical and administrative assistance he provided and his constant presence made it possible for me to fulfil aim of the study.

Also, I want to extent my sincere thanks to co-supervisor **Dr. J. A. Thamboo** at the South Eastern University of Sri Lanka for his guidance, for always standing as a true mentor throughout my research career, and for "opening the door for discussion" on any topic whenever I needed it and enlightened the contretemps. Equally, I would want to sincerely thank my co-supervisor **Prof. K. K. Wijesundara** at the University of Peradeniya, for his encouragement, untiring technical advice, constructively critical comments during the progress meetings and contributions significantly helped to achieve the aim of this study.

Next, I would also like to thank **Emeritus Prof. W. P. S. Dias** of the University of Moratuwa for serving as chairperson of the progress review committee and providing timely feedback on this project. I should also mention **Dr. T. M. N. Wijayaratna** for his support in the progress review meetings.

I wish to thank the Faculty of Graduate Studies, the University of Moratuwa for the opportunity to pursue my postgraduate studies. Also, I would like to acknowledge the financial assistance from the **National Academy of Sciences of Sri Lanka (NASSL)** in laying a foundation for my dream of a postgraduate research career. I also like to acknowledge that some of the school field surveys were funded by the **UK Global Challenge Research Fund project ReSCOOL** (Resilience of Schools to Extreme Coastal FlOOding Loads), awarded to **Prof. Tiziana Rossetto**, from University College London, by Research England; award No. 177813.

Moreover, I want to thank **Jonas Cels**, a doctoral candidate at University College London, for enlightening the OpenSees programme and clearing doubts at any time. The school building data acquisition would have been impossible without the help of E15 undergraduate students from the Department of Civil Engineering, South Eastern University of Sri Lanka: **B. M. N. D. Basnayaka**, **S. M. Faheem**, **A. Madursan**, **B. B. B. S. Bandara**, **D. G. H. S. Kalpage**, **D. M. N. S. Dasanayake**, and **T. P. A. Punyawardana**. I thank them all for their contributions to this study.

Last but far from least, I want to thank my family members and friends for their encouragement and immense patience until the end of this work.

# ABSTRACT

Sri Lanka is considered as an aseismic country, hence the seismic risk is not explicitly considered in the planning and designing of critical structures. However, current studies indicate that the seismic risk cannot be completely omitted when designing buildings in Sri Lanka, particularly post-disaster structures like schools and hospitals that should be designed to withstand any potential seismic action. Meanwhile, assessing the seismic risk of all the critical structures in depth across Sri Lanka might not be an easy task, and therefore, the creation of a rapid assessment method would help to effectively screen the buildings which are seismically vulnerable.

Therefore, in this study, an attempt was made to assess the seismic vulnerability of school buildings in Sri Lanka in detail by incorporating possible variations and proposing an alternate Rapid Visual Screening method (RVS) for Sri Lankan conditions by incorporating FEMA P-154 guidance.

In order to study the existing school building typologies, detailed structural surveys were carried out across Sri Lanka in selected school buildings. The survey revealed that school buildings in Sri Lanka can be characterised as reinforced concrete (RC) frames, infilled with unreinforced masonry walls (MI). Based on the structural configurations, mainly two building typologies were found as (1) Type 01 and (2) Type 02. Nonetheless, in terms of MI arrangements, it was observed that significant variations exist among the school buildings. Therefore, those variabilities were explicitly taken to assess the seismic performance of MI-RC school buildings.

The seismic performance of the school buildings was analysed using the OpenSees (OS) finite element programme. The torsional effects and post-processing as shear capacity and stochastic material properties (concrete, steel, and masonry) from Monte-Carlo simulation were incorporated in this study. The modal analysis and non-linear static pushover analysis were carried out, in which a total of 640 building cases were analysed.

The analyses of pushover (PO) and seismic fragility revealed that the Type 02 buildings exhibit significantly better performance than the Type 01 buildings. Also, the variation in MI arrangements significantly influences the seismic resistance of the buildings. In addition, the application of the proposed RVS method is effective to carry out the seismic screening method of school buildings in Sri Lanka.



**Keywords:**
School buildings, Non-linear static pushover, Seismic performance assessment, Seismic Fragility assessment and Rapid visual screening method

# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| *ADRS* | - | Acceleration Displacement Response Spectrum |
| *ATC* | - | Applied Technology Council |
| *CC* | - | Capacity Curve |
| *CDS* | - | Capacity Demand Spectrum method |
| *CF* | - | Collapse Factors |
| *CW* | - | Central Window |
| *d* | - | Displacement |
| *Du* | - | Ultimate displacement |
| *DW/SW* | - | Doubly or Single thickness masonry wall |
| *Dy* | - | Yield displacement |
| *FEMA* | - | Federal Emergency Management Agency |
| *FGS* | - | Fully closed Ground Storey |
| *HAZUS* | - | Hazard in United States |
| *HO* | - | Half Opening wall |
| *IEP* | - | Initial Evaluation Procedure |
| *ISA* | - | Initial Seismic Assessment |
| *JBDPA* | - | Japan Building Disaster Prevention Association |
| *MCS* | - | Monte-Carlo Simulation |
| *METU* | - | Metropolitan Municipality of Istanbul |
| *MI* | - | Masonry Infills |
| *NBS%* | - | New Building Standard percentage |
| *NLSPA* | - | Non-Linear Static Pushover Analysis |
| *NRCC* | - | National Building Council of Canada |
| *NSI* | - | Non-Structural Index |
| *OGS* | - | Open Ground Storey |
| *OS* | - | OpenSees |
| *PC* | - | Precast Concrete |
| *PO* | - | Pushover |
| *QO* | - | Quarter Opening wall |
| *RC* | - | Reinforced Concrete |
| *RC-MI* | - | Masonry Infilled Reinforced Concrete |
| *RM* | - | Reinforced Masonry |
| *RVS* | - | Rapid Visual Screening |
| *S02/S03* | - | Three or Two Storey |
| *Sa* | - | Spectral Acceleration |
| *Sd* | - | Spectral Displacement |
| *SI* | - | Structural Index |
| *T01/T02* | - | Type-01 or Type-02 buildings |
| *TO* | - | Three-quarter Opening wall |
| *URM* | - | Unreinforced Masonry |
| *V* | - | Base Shear |