THE IMPLICATIONS OF ADOPTING EUROCODES FOR DESIGNING DISASTER RESILIENT BUILDINGS IN SRI LANKA

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Thesis submitted in partial fulfillment of the requirements for the degree

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DECLARATION OF THE CANDIDATE

I declare that this is my own work and this thesis 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 another person except where the acknowledgement is made in the text. I retain the right to use this content in whole or part in future works (such as articles or books).

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DEDICATION

I would like to dedicate this thesis to the professional engineers in Sri Lanka, who endeavor to make sure safety, and disaster resilience in both new and existing built environments, benefiting the general public of Sri Lanka.

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ABSTRACT

Sri Lanka has prioritized designing disaster-resilient buildings and evaluating the degree of disaster-resilience of the existing buildings due to the challenges posed by natural and man-made hazards. This approach challenges the common practice of the Sri Lankan construction industry to use British Standards as its industrial standards. Since the British Standards had been replaced by Eurocodes, Sri Lanka has started using Eurocodes but without critically evaluating the effectiveness of Eurocodes and national annexes in designing buildings with disaster resilience features. Therefore, it is crucial to evaluate the structural vulnerability of buildings to gravity, wind, and seismic loads. To fulfill these timely needs, this study envisages to examine the effectiveness of Eurocodes and national annexes to design disaster-resilient buildings in Sri Lanka, assessing the degree of disaster resilience of the existing buildings, and examining cost implications. To this end, this study put forwards a novel framework to evaluate the structural resilience of code-compliant and non-code-compliant reinforced concrete buildings under extreme wind and seismic loads. The framework constitutes non-linear static pushover analysis for wind assessments, non-linear dynamic time-history analysis, incremental dynamic analysis, and fragility assessments for seismic evaluations. The framework was first applied to a typical office building before assessing a three-story school building, an eight-story university building, and a six-story hospital building, designed according to Eurocodes (EN1990. (2005), EN 1991-1-1. (2002), EN 1991-1-4. (2010), EN 1992-1-1. (2004), EN 1998-1. (2013)) and Sri Lankan national annexes, as well as a seven-story mixed-use defective building and its retrofitted version. The results showed that the Eurocode-based building designs have a significantly larger base shear capacity than the base shear force triggered by a wind with a 1700-year return period, the highest return period considered for the wind performance evaluation. Although these buildings have reasonable structural resilience against extreme seismic loading, they do not meet the more stringent performance requirements, such as Fully Operational and Operational, in the seismic performance objectives. Therefore, Eurocode-based designs can sometimes fail to meet the performance objectives for structural resilience, even though these objectives are assumed to be implicitly satisfied by the design codes and standards. The analysis of the defective building confirmed the building's inadequate capacity to carry gravity, wind, and seismic loads. The retrofitted building with structural jacketing had enhanced load carrying capacities, indicating the effectiveness of structural jacketing as a retrofitting measure for defective buildings in Sri Lanka. The comparison of material properties, partial safety factors, load combinations, and design methodologies of Eurocodes and British Standards for designing beams and columns revealed that British Standards generally require more reinforcement for a given section size, mainly due to more conservative partial safety factors in load combinations. However, the differences in section sizes and reinforcement requirements strongly depend on the building type and loading conditions, such as gravity loading alone or a combination of gravity and lateral loading.

Keywords: Eurocodes, Buildings, Disaster resilience, Wind loading, Seismic loading

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LIST OF ABBREVIATIONS

Abbreviation	Description
AEL	Annual Expected Loss
ASCE	American Society of Civil Engineers
ATC	Applied Technology Council
BSI	British Standards Institution
BSSC	Building Seismic Safety Council
CIDA	Construction Industry Development Authority
COV	Coefficient of Variation
CPT	Cone Penetration Test
CTBUH	Council on Tall Buildings and Urban Habitat
DDI	Deformation Damage Index
DM	Damage Measure
DOL	Duration of Load
DV	Decision Variable
EC	Eurocode
EDP	Engineering Demand Parameter
EN	Euro Norms
EU	European Union
FEMA	Federal Emergency Management Agency
FO	Fully Operational
FPHLM	Florida Public Hurricane Loss Model
GDP	Gross Domestic Product
IBC	International Building Code
IDA	Incremental Dynamic Analysis
IM	Intensity Measure
ISO	International Organization for Standardization
LRFD	Load and Resistance Factor Design
LS	Life Safe
MEP	Mechanical, Electrical, Plumbing

MRI	Mean Recurrence Interval
MWFRS	Main Wind Force Resisting System
NBRO	National Building Research Organization
NC	Near Collapse
NDTHA	Non-linear Dynamic Time-History Analysis
NEHRP	National Earthquake Hazards Reduction Program
NSPA	Non-linear Static Pushover Analysis
O	Operational
OMRF	Ordinary Moment Resisting Frame
PBD	Performance-Based Design
PBEE	Performance-Based Earthquake Engineering
PBWE	Performance-Based Wind Engineering
PEER	Pacific Earthquake Engineering Research
QST	Quenched and Self-Tempered
RB	Reinforcement Bar
RC	Reinforced Concrete
RMS	Root of Mean Squares
SDOF	Single Degree of Freedom
SEAOC	Structural Engineers Association of California
SL	Sri Lankan
SMRF	Special Moment Resisting Frame
SPT	Standard Penetration Test
UBC	Uniform Building Code
UDA	Urban Development Authority
UK	United Kingdom
UNDRR	United Nations Office for Disaster Risk Reduction
UNISDR	United Nations International Strategy for Disaster Reduction
US	United States Dollar

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