SEISMIC RESPONSE MODIFICATION FACTOR FOR REINFORCED CONCRETE FRAMES BASED ON NON-LINEAR PUSHOVER ANALYSIS AND TIME HISTORY ANALYSIS

By

RASHA ATTIA AHMED ATTIA

A Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of Master of Science in structural engineering

Under Supervision of

Dr. BAHAA SHARF TORK

Associate professor
Structural Engineering Department
Ain Shams University

Dr. MARWAN SHEDID

Associate professor
Structural Engineering Department
Ain Shams University

Dr. EZZ EL DEEN MOSTAFA ARAFA

Lecturer
Structural Engineering Department
Ain Shams University

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Thesis Approval

Examiners Committee	**Signature**
Dr. Mohamed Nour Eldin Fayed Professor of Structural Analysis Structural Engineering Department, Ain Shams University	……….….
Dr. Hala Mohamed Gamal Eldin Elkady Professor and Head of Civil Department National Research Center	……….….
Dr. BAHAA SHARF TORK Associate professor of Structural Analysis Structural Engineering Department, Ain Shams University	……….….

STATEMENT

This thesis is submitted in partial fulfillment of the requirements for the degree of Master of Science in Structural Engineering, Faculty of Engineering, Ain Shams University.

The author carried out the work included in this thesis, and no part of it has been submitted for a degree or a qualification at any other scientific entity.

Student Name

Rasha Attia Ahmed Attia

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TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

LIST OF ABBREVIATIONS AND SYMBOLS

- R: Response Reduction/Modification Factor
- RC: Reinforced Concrete
- MRF: Moment Resisting Frame
- SMRF: Special Moment Resisting Frame
- OMRF: Ordinary Moment Resisting Frame
- μ : Ductility Capacity
- R_{μ}: Ductility Factor
- R_s: Over-Strength Factor
- R_{ξ}: Damping Factor
- R_R: Redundancy Factor
- FB: Force-Based
- DB: displacement-Based
- DBE: Design Basis Earthquake
- Q_{ult} : Ultimate Base Shear
- Q_y : Yield Base Shear
- Q_{cr} : Base Shear At First Crack
- Δ_{max} : Chosen Maximum Displacement Limit
- Δ_{ult}: Maximum Displacement
- Δ_y: Yield Displacement
- Δ_w: working Displacement
- F_{cu}: concrete Compressive Strength
- f_y: Steel Yield Stress
- Es: Steel Young's Modulus
- Ec: Concrete Young's Modulus
- EPP: Elastic-Perfectly Plastic
- SDOF: Single-Degree-Of-Freedom
- V_e: Max elastic Base Shear
- V_d: Design Base Shear

- V_u: Maximum Base Shear
- IO: Immediate Occupancy
- LS: Life Safety
- RFT: Reinforcement
- ECP: Egyptian Code Of Practise
- BCP: British Code Of Practise
- UBC: Universal Building Code
- ASCE: American Society of Civil Engineers
- I.S.: Indian Standards
- SBC: Saudi Building Code
- NZS: New Zealand Code
- ATC: Applied Technology Council
- BF: Bare Frame

ABSTRACT

In many countries and regions in the world, earthquakes are one of the most common natural disasters, which affect human life and property. To avoid the negative effects of earthquakes(EQs), the nonlinear response of structures under dynamic loading should be accurately modelled to investigate their actual behaviour under earthquake loading to ensure safe and economic design.

Most seismic design codes today include the structure nonlinear response implicitly through a ‘response reduction/modification factor’(R). This factor allows a designer to use linear elastic force based method while representing nonlinear behaviour and deformation limits. This research focuses on estimating the actual values of this factor for reinforced concrete(RC) moment resisting frames, which were designed and detailed according to the ECP and ASCE code standards for seismic and comparing these values with the value proposed in the design code.

A total of 64 analytical models for RC frames analysis models using push over analysis and time history analysis. The models were chosen to study the effect of number of stories, and relative inertia between girders and columns on the expected R factors for RC frames. Then calculated response reduction/modification factors (R) for reinforced concrete (RC) frames will be compared to those specified in ECP and the ASCE code. The software used in this study is Seismostruct 2016.

The research was carried out over three phases. The first was a review of previous literature related to the focus of the study. This was carried out in order to have a clear and broad understanding of past findings in this field. During the second phase, a technique for reinforced concrete(RC) frames modelling was developed and the experimental results of previous studies available in literature were verified. In the final phase, a parametric study was created to study the effect of number of stories, and relative inertia between girders and columns on the expected R factors for RC frames. Then calculated response reduction/modification factors(R) for reinforced concrete(RC) frames will be compared to those specified in ECP and the ASCE code.

The results show that:

1- The response reduction/modification factor(R) value is sensitive to both number of stories and relative inertia between girders and columns, however variation in relative inertia between girders and columns tend to display more significant impact on R-value.
2- The effect of increasing number of stories on decreasing the R value is more significant, compared to the value recommended in the design codes which equal to 5 according to ECP and ASCE for intermediate moment resisting frame .
3- Increasing number of stories lead to lower ductility factor. And also increasing the relative inertia between girders and columns lead to lower ductility factor too.
4- The calculated R-values for mid-rise buildings were higher than these values in ECP code and ASCE code, which lead to a lower base shear that wasn't considered in codes.
5- While the number of stories increases from(2,4,8 and 12 stories), the R factor calculated based on ($R\mu=\mu$),tends to decrease by (11%, 36% to 52%) respectively for the relative inertia between girders and columns equals to 1:1, (14%, 46% to 58%) respectively for the relative inertia between girders and columns equals to 1:2 and (32%, 54% to 64%) respectively for the relative inertia between girders and columns equals to 1:4.
6- While the relative inertia between girders and columns increases from (1:1, 1:2 to 1:4), the ductility factor tends to decrease by (1.3% to 3%) respectively for 2stories analysis model,(3.7% to 26%) respectively for 4stories analysis model ,(16% to 31%) respectively for 8stories analysis model and(12.5% to 26%) respectively for 12stories analysis model.
7- The response reduction/modification factor(R) value, calculated based on ($R_\mu= \sqrt{2\mu - 1}$), for 2 stories analysis models using pushover analysis is low compared to time history analysis because the ductility

factor depends on the fundamental period which has a value lower than 0.5 second in pushover analysis.

8- The time period calculated based on ECP code doesn't take into consideration the mass and the stiffness of the RC structures as the fundamental period calculated based on structural mechanics.

9- While the relative inertia between girders and columns increase, the fundamental period calculated based on structural mechanics decrease.

10- The R –values based on ($R_\mu=\mu$) from pushover analysis and time history analysis are approximately the same.

A number of conclusions and recommendations for future work were extracted from this study. The conclusions were related to the modelling of reinforced concrete (RC) frames and to the system level behaviour under lateral loading.

Key words: Pushover analysis, Time history analysis, Reduction modification factor.

CHAPTER 1: INTRODUCTION

Experience in previous earthquakes (EQs) has demonstrated that many common buildings and typical construction methods lack fundamental resistant of the EQ forces, so that the concept of seismic design has been developed. The basic approach of seismic design should be based on lateral strength as well as ductility and deformability capacity of reinforced concrete(RC) structure with specific level of damage while preventing collapse. Therefore one of the main tasks of the structural designer is to ensure that reinforced concrete(RC) structure possess enough strength and ductility to resist the expected levels of EQs during its lifetime.

In design codes, the non-linearity of structures in linear analysis is indirectly considered by reducing the seismic base shear of RC structures with a factor that defined as the response reduction/modification factor(R). Pushover & non linear time history analyses could be used for better estimate of the seismic demand of the RC structures.

To yield proper results, accurate representative structural models should be developed for the elements resisting lateral loading and representative EQs pertaining to the site should be employed. Then relating such response to that of elastic behaviour should be conducted to correlate response reduction/modification factor(R) in design codes with actual response.

Based on the literature review, there are two approaches in this research, one approach is by applying pushover analysis, and the other approach is by applying time history analysis.

1.1 RESEARCH MOTIVATION

Reinforced concrete(RC) structures are able to dissipate a large amount of energy during EQ. RC structures designed to withstand EQs must have enough stiffness and strength to prevent any possible collapse and control deflection. Most recent codes of seismic include response reduction/modification factor(R) in definition of equivalent lateral forces used for seismic design of structures to reduce elastic design spectral acceleration of the RC structure to account for the capacity of energy dissipation. The