# A Systematic Approach for Seismic Evaluation and Retrofit of RC Buildings in Severe Earthquake Prone Area

**Thesis submitted in partial fulfillment**

**for the Award of Degree**

*Doctor of Philosophy*

**by**

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**August 2022**

***"I would like to dedicate this thesis***
***to my Parents,***
***For their endless love, support and encouragement"***

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It is certified that the work contained in the thesis titled **"A Systematic Approach for Seismic Evaluation and Retrofit of RC Buildings in Severe Earthquake Prone Area"** by **Mangeshkumar Rajkumar Shendkar** has been carried out under our supervision and this work has not been submitted elsewhere for a degree.

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Mangeshkumar Rajkumar Shendkar

# Abstract

The Indian subcontinent has experienced some of the greatest earthquakes in the world. Several major earthquakes created huge deaths and significant property damage. One of the most important global examples of reservoir-induced seismicity is the Koyna-Warna region of Maharashtra, India. The area is highly vulnerable to earthquakes and it has experienced over 1 lakh number of shocks since 1963. The largest known earthquake of magnitude 6.5 (Richter scale) occurred on 10$^{th}$ December 1967. Many low and moderate earthquake events have occurred over the past 50 years. The rapid visual screening (RVS) of 120 existing RC buildings has been carried out through EDRI method to evaluate the seismic risk index of the Koyna-Warna region (Zone-IV as per IS 1893 Part-1:2016). Based on the survey, it is observed that many existing RC buildings in the Koyna-Warna region are designed without seismic resistant provisions. Hence, there is a need to study the seismic risk index of these RC buildings to assess future seismic risks. The seismic risk index depends on three parameters, viz., hazard, exposure, and vulnerability. In the present study, "Quadrants assessment method" and "Material strain limit approach" are proposed and numerically investigated for the detailed seismic assessment. The "Quadrants assessment method" is a global and quick approach to check the need of intervention or retrofit the structures. This method is based on the actual response reduction factor, performance point, design base shear, and threshold damage limit state. Material strain limit approach is an effective method to identify the actual damage state of structural members. Based on the RVS study, it was found that a total of seventeen reinforced concrete buildings are vulnerable to seismic events. These buildings are evaluated with nonlinear static adaptive pushover analysis by using the SeismoStruct software and the retrofit strategies have been suggested to deficient buildings. Also, the

significant seismic design parameters, viz., ductility, overstrength factor, response reduction factor, etc. are evaluated before and after the retrofit.

The Koyna-Warna region has 46.7 % of reinforced concrete surveyed buildings are falling in the possible collapse category. This is because many buildings are constructed as a non-engineered in a hilly region, most of the buildings are old and the region experiences heavy rainfall. About 0.8 % and 21.7 % of surveyed buildings are falling in no damage and slight damage condition. The percentage of RC buildings in moderate and severe damage stage is 10.8 % and 20 % respectively. Also, irregular plan shapes, inadequate lintel and sill bands, cracks in structural members, vegetation on the wall are the common observations in RC buildings that make them seismically more vulnerable.

Model-1, 15, and 17 are retrofitted with RC jacketing, while the other remaining RC buildings do not need to be retrofitted due to their inherent structural integrity based on the Quadrants assessment method. The results depict that there is a need to take initiatives for earthquake preparedness plan, with emphasis on retrofitting measures in Koyna-Warna region to reduce the loss of human life and damage to infrastructure in future seismic events. The computed values of the response reduction factor (R) are more than the value suggested in the IS 1893 (Part-1):2016 code for RC-infilled structures. The over-strength factor is significantly influenced by the presence of masonry infills in the RC frame. As a result, the response reduction factor is higher in the RC-infilled structure. The ultimate capacity, overstrength factor, response reduction factor of the retrofitted buildings are significantly increased in the X and Y direction as compared to the unretrofitted buildings, due to the application of RC jacketing to deficient column members. Based on the present study, it is concluded that the combination of the “Quadrants assessment method” and “Material strain limit approach” is a rapid, reliable

and refined procedure for the seismic evaluation and retrofit of reinforced concrete buildings.

***Keywords*:** Adaptive pushover analysis; Earthquake Disaster Risk Index (EDRI) method; Quadrants assessment method; Material strain limit approach; Response reduction factor; Performance point; Retrofit, Reinforced concrete buildings, Masonry infill, Earthquake Prone area.

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## List of Symbols

| | |
|---|---|
| $R$ | Response reduction factor |
| $R_d$ | Ductility reduction factor |
| $R_o$ | Overstrength factor |
| $R_R$ | Redundancy factor |
| $\mu$ | Ductility |
| $V_u$ | Ultimate strength |
| $V_d$ | Design base shear |
| $\Delta_{max}$ | Maximum displacement |
| $\Delta_y$ | Yield displacement |
| $\delta_t$ | Target displacement |
| $C_O$ | Modification factor calculated from displacement of building |
| $C_1$ | Modification factor used to relate the expected maximum inelastic to elastic displacement |
| $C_2$ | Modification factor corresponds to impact of strength deterioration, cyclic stiffness degradation |
| $S_a$ | Response spectral acceleration |
| $T_e$ | Effective time period |
| $\alpha$ | Site class factor |
| $\beta$ | Effective viscous damping |
| $W$ | Seismic weight |
| $T_s$ | Characteristic period of the response spectra |
| $T_o$ | Period correlated with the variable acceleration segment of spectra |
| $S_{xs}$ | Spectral response acceleration at 0.2 sec |
| $S_{x1}$ | Spectral response acceleration at 1 sec |

| | |
|---|---|
| ø | Diameter of steel |
| $F_a$ & $F_v$ | Site dependent coefficients |
| $S_s$ | Mapped spectral acceleration at short period |
| $S_1$ | Mapped spectral acceleration at long period |
| $S_{DS}$ | Design spectral response acceleration at short period |
| $S_{D1}$ | Design spectral response acceleration at long period |
| $S_{MS}$ | Maximum considered earthquake spectral response acceleration at short period |
| $S_{M1}$ | Maximum considered earthquake spectral response acceleration at long period |
| $W_d$ | Width of the diagonal strut |
| $W_{do}$ | Width of the diagonal strut with opening in infill |
| $A_r$ | Ratio of the opening area to the face area of infill |

## Abbreviations

| | |
|---|---|
| 3D | Three Dimensional |
| 2D | Two Dimensional |
| CCP | Current Construction Practise |
| NBC | National Building Code |
| WDS | Well Designed Structure |
| ISD | Interstorey Drift |
| NEHRP | National Earthquake Hazard Reduction Program |
| URM | Unreinforced Masonry |
| FEMA | Federal Emergency Management Agency |
| BIS | Bureau of Indian Standards |
| SERC | Structural Engineering Research Centre |
| ASCE | American Society of Civil Engineers |
| UNIDO | United Nations Industrial Development Organization |
| RVS | Rapid Visual Screening |
| FRB | Fuzzy Rule Based |
| SMRF | Special Moment Resisting Frame |
| OMRF | Ordinary Moment Resisting Frame |
| EDRI | Earthquake Disaster Risk Index |
| NDMA | National Disaster Management Authority |
| LTF | Life Threatening Factor |
| ELIF | Economic Loos Inducing Factor |
| RC | Reinforced Concrete |
| SRSS | Square Root of Sum of Squares |

| | |
|---|---|
| DBE | Design Basis Earthquake |
| MCE | Maximum Considered Earthquake |
| FRP | Fibre Reinforced Polymer |
| ZPA | Zero Period Acceleration |
| DCR | Demand Capacity Ratio |
| FAR | Floor Area Ratio |
| NDT | Non-Destructive Test |